CHAPTER 9.
POTENTIAL HEALTH AND WELFARE BENEFITS OF REGIONAL HAZE REDUCTIONS

9.1 Results in Brief

Monetary benefits are calculated for the four illustrative Regional Haze (RH) visibility goals under two emission control cases. Incremental benefits (in 1990$) from progress towards improved visibility goals for the emission control case (Case A) including fugitive dust controls are expected to range from $0 (if all regions choose to set a goal equal to the progress attainable from implementation of the particulate matter (PM) and Ozone National Ambient Air Quality Standards (NAAQS) or if the visibility goal is fully achieved by all regions after implementation of the PM and Ozone NAAQS) to $18.7 billion. For the individual goals, the estimated benefits if all areas adopt the same goal are $3.0 to $7.0 billion for the 1.0 dv/10 years goal, $2.2 to $5.5 billion for the 1.0 dv/15 years goal, $5.1 to $18.6 billion for the 10% dv/10 years goal, and $2.7 to $6.7 billion for the 5% dv/10 years goal. Visibility benefits account for between 12 and 52 percent of total benefits, depending on the visibility goal and the health effects threshold level assumed. The range of benefits for an individual region may differ from the range for the nation as a whole. If a region completely achieves or surpasses a visibility goal through implementation of the PM or Ozone NAAQS, then the incremental benefits from the RH rule will be zero.

Incremental benefits (in 1990$) from progress towards improved visibility goals for the emissions control case (Case B) excluding fugitive dust controls are expected to range from $0 (for the same reasons as above) to $19.4 billion. For the individual goals, the estimated benefits if all areas adopt the same goal are $2.1 to $9.7 billion for the 1.0 dv/10 years goal, $1.2 to $4.3 billion for the 1.0 dv/15 years goal, $3.5 to $19.4 billion for the 10% dv/10 years goal, and $2.0 to $9.4 billion for the 5% dv/10 years goal. Visibility benefits account for between 8 and 58 percent of total benefits, depending on the visibility goal and the health effects threshold level assumed.

This benefits analysis does not quantify all potential benefits or disbenefits. The magnitude of the unquantified benefits associated with omitted categories, such as damage to ecosystems or damage to industrial equipment and national monuments, is not known. However, to the extent that unquantified benefits exceed unquantified disbenefits, the estimated benefits presented above will be an underestimate of actual benefits. The methods for estimating monetized benefits for the RH rule and a more detailed analysis of the results are presented below.

9.2 Introduction

The changes in emissions and associated changes in light extinction and ambient PM concentrations described in Chapter 4 will result in changes in the physical damages associated with elevated ambient concentrations of these pollutants. The damages include changes in both human health and welfare effects categories.

This chapter presents the methods used to estimate the physical and monetary benefits of the modeled emissions changes from implementing illustrative goals for visibility improvements at Federal Class I areas, including national parks and wilderness areas. In addition, the estimates of the avoided physical damages (e.g., incidence reductions), and the results of the benefits analysis for a range of alternative goals are presented. Results are presented for the four potential visibility goals described in Chapter 3. Results are presented twice, once for each emission control case described in Chapter 3. Benefits are calculated for the nation as a whole, assuming that a particular goal is adopted across the nation. Additional estimates of the benefits of regionally determined visibility goals are summarized in this chapter and analyzed further in Chapter 10, Benefit-Cost Comparisons.

The remainder of this chapter is laid out as follows. Section 9.3 provides an overview of the benefits methodology. Section 9.4 discusses methods for estimating the monetary benefits associated with changes in visibility. Section 9.5 discusses methods for estimating avoided incidences and monetary benefits for PM-related health and welfare effects. Section 9.6 provides estimates of visibility and ancillary health and welfare benefits associated with alternative visibility goals using emission control Case A. Section 9.7 provides estimates of visibility and ancillary health and welfare benefits associated with alternative visibility goals using emission control Case B. Section 9.8 summarizes total benefits for the four illustrative goals and the two emission control cases. Section 9.9 provides a set of plausibility checks of the benefits estimates. Finally, Section 9.10 discusses potential benefit categories that are not quantified due to data and/or methodological limitations, and provides a list of analytical uncertainties, limitations, and biases.

9.3 Overview of Benefits Estimation

Most of the specific methods and information used in this benefit analysis are similar to those used in the §812 Retrospective of the Benefits and Costs of the Clean Air Act and forthcoming §812 Prospective Environmental Protection Agency (EPA) Reports to Congress, which were reviewed by EPA's Science Advisory Board (EPA, 1997b), as well as building on the approach used by EPA in the PM and Ozone NAAQS RIA (EPA, 1997a) and in the NOx SIP call and Proposed Tier 2 RIAs (EPA, 1998a and EPA, 1999a), which received extensive review by other Federal agencies.

Prior to describing the details of the approach for the benefits analysis, it is useful to provide an overview of the approach. The overview is intended to help the reader better identify the role of each issue described later in this chapter.

The general term "benefits" refers to any and all outcomes of the regulation that are considered positive, that is, that contribute to an enhanced level of social welfare. The economist's meaning of "benefits" refers to the dollar value associated with all the expected positive impacts of the regulation, that is, all regulatory outcomes that lead to higher social welfare. If the benefits are associated with market goods and services, the monetary value of the benefits is approximated by the sum of the predicted changes in "consumer (and producer) surplus." These "surplus" measures are standard and widely accepted measures in the field of applied welfare economics, and reflect the degree of well being enjoyed by people given different levels of goods and prices. If the benefits are non-market benefits (such as the risk reductions associated with environmental quality improvements), however, other methods of measuring benefits must be used. In contrast to market goods, non-market goods such as environmental quality improvements are public goods, whose benefits are shared by many people. The total value of such a good is the sum of the dollar amounts that all those who benefit are willing to pay.

In addition to benefits, regulatory actions may also lead to potential disbenefits, i.e., outcomes that have a negative impact on social welfare. In general these disbenefits will be incidental to the stated goals of the regulation, otherwise (in an efficient regulatory environment) the regulation would not have been promulgated. Some benefits will also be incidental to the stated goals of the regulation. For example, the goal of the RH rule is improved visibility, however, improvements in visibility will also result in reduced PM related health effects. In order to fully quantify the benefits and costs of a regulatory action, both the benefits and disbenefits should be calculated, so that net benefits (equal to benefits minus disbenefits minus costs) will not be biased upwards. In many cases, however, disbenefits are difficult to quantify, as it is often unclear where and how disbenefits will occur. Benefits may also be difficult to quantify, since many benefits are not measurable using market based measures. The EPA's approach is to present as complete a set of quantified and monetized estimates of benefits and disbenefits as possible, given the current state of science at the time of the analysis.

This conceptual economic foundation raises several relevant issues and potential limitations for the benefits analysis of the regulation. First, the standard economic approach to estimating environmental benefits is anthropocentric -- all benefits values arise from how environmental changes are perceived and valued by people in present-day values. Thus, all near-term as well as temporally distant future physical outcomes associated with reduced pollutant loadings need to be predicted and then translated into the framework of present-day human activities and concerns. Second, as noted below, it is not possible to quantify or to value all of the benefits or disbenefits resulting from environmental quality improvements.

Conducting a benefits analysis for anticipated changes in air emissions is a challenging exercise. Assessing the benefits of a regulatory action requires a chain of events to be specified and understood. As shown in Figure 9-1, illustrating the causality for air quality related benefits, the estimation of benefits requires information about: (1) institutional relationships and policy-making; (2) the technical feasibility of pollution abatement; (3) the physical-chemical properties of air pollutants and their consequent linkages to biological or ecological responses in the environment, and (4) human responses and values associated with these changes.

The first two steps of Figure 9-1 reflect the institutional and technical aspects of implementing the RH regulation (the improved process changes or pollutant abatement). The estimated changes in light extinction or ambient PM are directly linked to the estimated changes in precursor pollutant emission reductions through the use of air quality modeling, as described in Chapter 6. For this analysis, steps 2 through 4 of Figure 9-1 play an important role in determining the total benefits associated with each illustrative goal.

As described in Chapter 4, two sets of emission reductions associated with two sets of available emission controls were developed for input into the source-receptor (S-R) matrix air quality model. In both cases, a number of counties with Class I areas were not able to achieve one or more of the illustrative visibility goals (see Tables 6-9 and 6-11 in Chapter 6). Thus, the benefits estimates will be for partial achievement nationwide of the illustrative visibility goals. If additional cost-effective controls were available such that all counties were able to achieve the illustrative visibility goals, estimated benefits would be higher. The number of counties not achieving the illustrative visibility goals is higher under emission control Case B relative to Case A. The difference ranges from five counties for the least stringent goal to fifteen counties for the most stringent goal. It is thus important to keep the level of compliance in mind when comparing benefits (and costs) both between visibility goals and between the two emission control cases. In essence, the actual goals modeled using the constrained least-cost strategy are different than the desired goals set for the analysis. Given that the actual goals achieved in the two emission control cases (Case A and Case B) differ both from the stated goal and from each other, a quantitative comparison of the benefits between cases is not recommended.

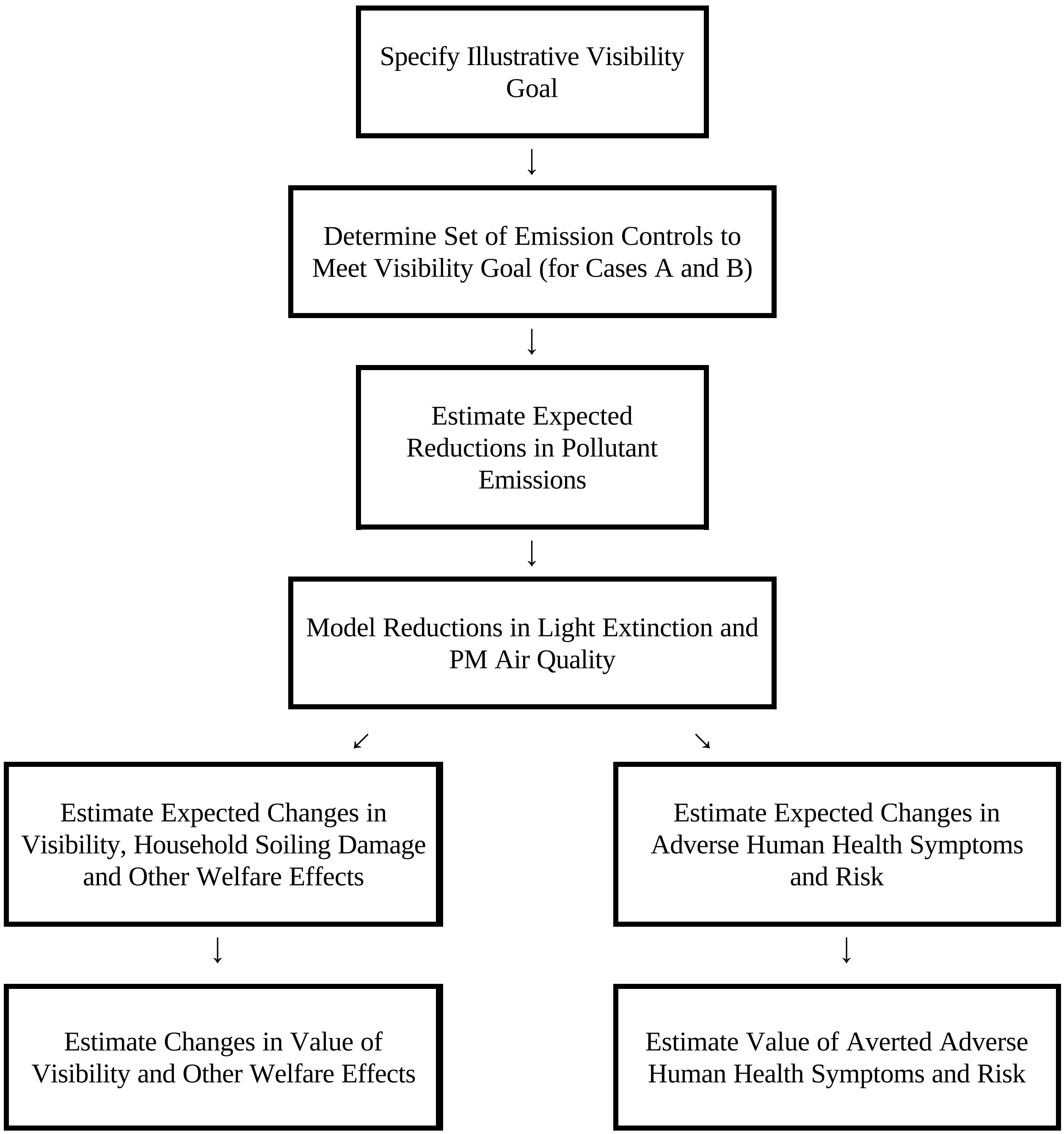
In addition to differences in the number of counties with deciview shortfalls, the types of emissions controlled differs between the two emission control cases. Relative to Case A, Case B (excluding fugitive dust emission controls) results in fewer reductions in PM_{10} and, for some goals, fewer reductions in directly emitted $PM_{2.5}$. Emissions of nitrogen oxides (NOx) and sulfur dioxide (SO_2) are reduced more in Case B relative to Case A. The composition of emissions reductions matters because PM related health benefits are highly dependent on the type of PM concentrations that are reduced, i.e. mortality is dependent on changes in $PM_{2.5}$ concentrations and chronic bronchitis is dependent on changes in PM_{10}. Therefore, given that Case B results in fewer reductions in PM_{10} we would expect to see lower benefits associated with reduced chronic bronchitis. In addition for those goals under Case B that have increased reductions in both directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors, we would expect to see higher benefits associated with reduced mortality. However, for those goals where directly emitted $PM_{2.5}$ increases and $PM_{2.5}$ precursor emissions decrease, the expected impact on mortality related benefits is ambiguous.

This analysis uses a "damage function" approach to estimate the adverse physical effects from air pollution that will be avoided in the United States due to implementation of the emission reductions required to achieve a specified visibility goal. This approach examines individual physical effects that may be affected by reductions in specific pollutants. An "economic unit value" approach is used (for most effect categories, e.g., premature mortality or chronic bronchitis) to estimate society's aggregate demand (i.e., willingness to pay (WTP) for avoiding each type of physical effect on a per-incidence level. Total value for a given physical effect is simply the product of the number of incidences avoided and the value per incidence avoided. The damage function approach assumes that benefits from individual endpoints are additive and independent, i.e., benefits for one endpoint do not depend on benefits for a separate endpoint. Alternative approaches include market-based measures such as hedonic prices, which measure the total value of a reduction in air pollution using a single metric, such as the marginal price of an environmental attribute embedded in the price of a house, or contingent valuation, which asks individuals for their total WTP for a reduction in air pollution. If the single metric approach successfully captures the full WTP for a reduction in air pollution, then the damage function approach should provide an estimate that is less than or equal to the estimate from the single metric approach. All dollar estimates of monetary benefits presented in this chapter are in 1990 dollars.

Some of the estimates of the economic value of avoided health and welfare effects are derived from contingent valuation (CV) studies. Concerns about the reliability of value estimates that come from CV studies have dominated debates about the methodology, since research has shown that bias can be introduced easily into these studies, especially if they are not carefully done. Accurately measuring willingness to pay for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP, 2) whether the good to be valued is comprehended and accepted by the respondent, 3) whether the WTP elicitation format is designed to minimize strategic responses, 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income, 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods, and 6) the extent to which WTP responses are consistent with established economic principles. This benefits analysis does not attempt to list the individual strengths and weaknesses of each CV study used, however, in some instances, such as for valuation of chronic bronchitis and residential visibility, when the CV study reliability can be questionable, we adopt alternative estimates as conservative measures of benefits, which are presented in the low-end estimate of the range of monetized benefits.

The valuation of avoided incidences of health effects and avoided degradation of welfare effects relies on benefits transfer. The benefits transfer approach takes values or value functions

Figure 9.1
Methodology for the Regional Haze Benefits Analysis



generated by previous research and transfers them from the study to the policy of interest. For example, the value of reduced mortality is obtained from a distribution of values of statistical life based on 26 wage-risk and contingent valuation studies. None of the values for the health and welfare categories valued in this benefit analysis were generated specifically for the RH rule. The validity of this approach relies on the correlation between the attributes of the policy and the studies from which the values were obtained. Where possible, studies were selected that valued endpoints matching those in the policy analysis. When studies were not available with exact matches between the studied endpoint and the policy endpoint, studies were selected to provide as close a match as possible and differences are noted in the text.

The first step in a benefits analysis using this approach is the identification of the types or categories of benefits associated with the anticipated changes in ambient air quality conditions. The second step is the identification of relevant studies examining the relationships between air quality and these benefit categories and studies estimating the value of avoiding damages. Table 9-1 provides an example of the types of benefits potentially observed as a result of changes in air quality. The types of benefits identified in both the health and welfare categories can generally be classified as use benefits or non-use benefits.

Use benefits are the values associated with an individual’s desire to avoid exposure to an environmental risk. Use benefits include both direct and indirect uses of affected ambient air, and embrace both consumptive and non-consumptive activities. In most applications to air pollution scenarios, the use benefits with the highest monetized value are those related to human health risk reductions, visibility, and materials damage.

Non-use (intrinsic) benefits are values an individual may have for lowering air pollution concentrations or the level of risk unrelated to his or her own exposure. Individuals apart from any past, present, or anticipated future use of the resource in question can value improved environmental quality. Such non-use values may comprise a significant portion of the total monetary benefits. However, the dollar amount to assign to these non-use values often is a matter of considerable debate. While human uses of a resource can be observed directly and valued with a range of technical economic techniques, non-use values often must be ascertained through indirect methods, such as asking survey respondents to reveal their values.

Non-use values may be related to the desire that a clean environment be available for the use of others now and in the future, or may be related to the desire to know that the resource is being preserved for its own sake, regardless of human use. The component of non-use value that is related to the use of the resource by others in the future is referred to as the bequest value. This value is typically thought of as altruistic in nature. For example, the value that an individual places on reducing the general population’s risk of PM exposure either now or in the future is referred to as the bequest value. Another potential component of non-use value is the value that is related to preservation of the resource for its own sake, even if there is no human use of the resource. This component of non-use value is sometimes referred to as existence value. An example of an existence value is the value placed on protecting the habitats of endangered species from the effects of air pollution, even if the species have no direct use to humans.

Table 9-1

Examples of Potential Benefits of Air Quality Improvements

USE BENEFITS	EXAMPLES
Direct	Human Health Improvements (e.g., less incidences of coughing)
Indirect	Non-Consumptive Use (e.g., improved visibility for recreational activities)
Option Value	Risk Premium for Uncertain Future Demand Risk Premium for Uncertain Future Supply (e.g., treating as insurance, the protection of a forest just in case a new use for a forest product will be discovered in the future)
Aesthetic	Residing, working, traveling, and/or owning property in reduced smog locations
NON-USE BENEFITS	
Bequest	Intergenerational Equity (e.g., an older generation wanting a younger generation to inherit a protected environment)
Existence	Stewardship/Preservation/Altruistic Values (e.g., individuals wanting to protect a forest even if they know that they will never use the forest) Ecological Benefits

The majority of health and welfare benefits categories included in this analysis can be classified as direct-use benefits. These benefits are discussed in greater detail than other benefits categories presented in Table 9-1 because more scientific and economic information has been gathered for the direct-use benefits category. Detailed scientific and economic information is not as readily available for the remainder of the potential benefits categories listed in Table 9-1. Information pertaining to indirect use, option value, aesthetic, bequest, and existence benefits is often more difficult to collect.

It is also difficult to identify all the types of benefits that might result from environmental regulation and to value those benefits that are identified. A cost analysis is expected to provide a more comprehensive estimate of the cost of an environmental regulation because technical information is available for identifying the technologies that would be necessary to achieve the desired pollution reduction. In addition, market or economic information is available for the many components of a cost analysis (e.g., energy prices, pollution control equipment, etc.). A similar situation typically does not exist for estimating the benefits of environmental regulation. This problem is due to the non-market nature of many benefit (or disbenefit) categories. Since many pollution effects (e.g., adverse health or ecological effects) traditionally have not been traded as market commodities, economists and analysts cannot look to changes in market prices and quantities to estimate the value of these effects. This lack of observable markets may lead to the omission of significant benefit (or disbenefit) categories from an environmental benefits analysis.

Because of the inability to quantify many of the benefits categories listed in Table 9-1, as well as the omission of unknown but relevant environmental benefits categories, the quantified benefits presented in this report may underestimate total benefits. It is not possible to quantify the magnitude of this underestimation. The more important of these omitted effect categories are shown in Table 9-2. Underestimation of total benefits may be mitigated to some extent if there are also relevant disbenefit categories that are omitted or unquantified.

Within each effect category, there may be several possible estimates of health and welfare effects or monetary benefit values. Each of these possibilities represents a health or welfare "endpoint." The basic structure of the method used to conduct the benefits analysis is to create a set of benefit estimates reflecting different key assumptions concerning environmental conditions and the responsiveness of human health and the environment to changes in air quality, as well as different assumptions about the values people place on changes in health and environmental quality. Total benefits are presented as a range representing the sensitivity of benefits over the set of maintained assumptions. The benefits range does not provide information on the likelihood of any set of assumptions being the correct one. Thus, while the range indicates the sensitivity of benefits to the various assumptions, it requires a subjective determination of which assumption set most closely represents reality.

The primary estimate and upper and lower ends of the range of total benefits are constructed using estimates of non-overlapping endpoints for each effect category, selected to avoid double counting. Double counting occurs when two endpoints contain values for the same thing. For example, an endpoint measuring avoided incidences of all hospital admissions would incorporate avoided incidences of hospital admissions just for heart disease. Thus, including values for avoiding both types of hospital admissions, would double count the value of avoided hospital admissions for heart disease.

Table 9-2
Unquantified Benefit Categories[a]

	Unquantified Benefit Categories Associated with PM
Health Categories	Changes in pulmonary function Morphological changes Altered host defense mechanisms Cancer Other chronic respiratory disease
Welfare Categories	Materials damage (other than consumer cleaning cost savings) Damage to ecosystems (e.g., acid sulfate deposition) Nitrates in drinking water

a Note that there are other pollutants that are reduced in conjunction with strategies implemented to reduce RH. These include ozone, carbon (a pollutant associated with global climate change) and mercury (a toxic pollutant). Co-benefits associated with these pollutant reductions are also not considered in this benefits analysis.

There are defensible alternatives to virtually every decision about the makeup of the plausible range. In order to better inform the reader of important alternative assumptions that could have been made, and to provide an understanding of the impact of each alternative on the overall assessment of the monetary benefits, the benefits analysis includes a number of quantitative sensitivity analyses. Sensitivity analyses for assumptions which affect multiple endpoints, such as the health effects threshold for PM-related health effects, are presented as part of the primary analysis for each affected endpoint. Sensitivity analyses which affect only aggregate benefits, such as calculation of total visibility benefits, will be incorporated into the plausible range and thus included as part of the presentation of total benefits.

Sensitivity analyses for alternative endpoints not included in the plausible range, such as premature mortality related to short-term PM exposures or asthma attacks, are presented in the technical support document for this Regulatory Impact Analysis (RIA) (Abt Associates, 1999).

Table 9-3 lists the specific health and welfare effects that are included in the benefits analysis, indicating the specific effect categories that are included in the plausible range of benefits. Also included in Table 9-3 are the estimates of mean WTP, or “unit values” used to monetize the benefits for each endpoint.

Table 9-3
Quantified and Monetized Health and Welfare Effects

Endpoint	Pollutant	Mean WTP per statistical incident ($1990)	
		Low-end	High-end
Health Risks Valued in the Benefits Analysis			
Mortality, Long-term Exposure - Over age 30	$PM_{2.5}$	$2,200,000	$4,800,000
Chronic Bronchitis - All Ages	PM_{10}	$59,000	$260,000
Hospital Admissions - All Respiratory, All Ages	$PM_{10}/PM_{2.5}$	$6,344	$6,344
Hospital Admissions - Congestive heart failure	PM_{10}	$8,280	$8,280
Hospital Admissions - Ischemic heart disease	PM_{10}	$10,308	$10,308
Acute Bronchitis - Children	$PM_{10}/PM_{2.5}$	$45	$45
Lower Respiratory Symptoms - Children	PM_{10}	$12	$12
Upper Respiratory Symptoms - Children	PM_{10}	$19	$19
Work Loss Days - Adult	$PM_{2.5}$	$83	$83
Minor Restricted Activity Days (MRAD) - Adult	$PM_{2.5}$	$38	$38
Welfare Effects Valued in the Benefits Analysis			
Household Soiling	PM_{10}	$2.52/household/ μg/m^3 change in PM_{10}	$2.52/household/ μg/m^3 change in PM_{10}
Visibility - Residential	Light Extinction[a]	___[b]	variable
Visibility - Select Class I areas	Light Extinction[a]	variable	variable
Nitrogen deposition to selected Eastern U.S. estuaries	NOx	$59 - $238/kg of nitrogen[d]	$59 - $238/kg of nitrogen[d]

[a] Measured in terms of deciview change.

[b] Residential visibility benefits not monetized for the low-end estimate of total benefits.

[c] California and Northwest: $12.89 in-region, $8.96 out-of-region; Southwest and Rocky Mountain: 16.82 in-region, $13.51 out-of-region; Southeast and Northeast/Central: $7.98 in-region, $4.91 out-of-region.

[d] Chesapeake Bay: $59/kg nitrogen, Albemarle-Pamlico Sound: $90/kg nitrogen, Tampa Bay: $238/kg nitrogen, Nine other estuaries: $129/kg nitrogen.

9.4 Valuing Changes in Visibility

Economic benefits may result from two different broad categories of visibility changes: (1) changes in "residential" visibility – including visibility in urban, suburban, and rural areas, as well as in recreational areas not listed as federal Class I areas; and (2) changes in "recreational" visibility – visibility at national parks and wilderness areas listed as federal Class I areas. A key difference in the two types of visibility benefits is that changes in visibility outside of Class I areas (residential visibility changes) are assumed to be valued only by populations in those areas, while changes in visibility in Class I areas (recreational visibility changes) are assumed to be valued by the entire U.S. population. However, within the category of recreational visibility, an individual's WTP for improvements in visibility in a national park may be influenced by whether the park is in the region in which the individual lives, or whether it is somewhere else. In general, people appear to be willing to pay more for visibility improvements at parks that are "in-region" than at parks that are "out-of-region." For additional details regarding the entire visibility analysis, refer to the technical support document for this analysis (Abt Associates, 1999).

The values for changes in residential and recreational visibility are derived from two contingent valuation (CV) studies, a study of residential visibility values conducted by McClelland, et al. in 1993 (based on a 1990 survey), and a study of recreational visibility values conducted by Chestnut and Rowe in 1990 (based on a 1988 survey). Contingent valuation is a rapidly developing field and new methodologies for study design and implementation are continually evolving. As such, studies developed in the late 1980's and early 1990's may differ in some elements of study design from more recent studies. The Chestnut and Rowe study has many properties of a reliable CV study, and EPA's judgement is that these are important enough properties to conclude that the study is useful for providing valuations associated with Class I area visibility improvements. The McClelland et al study has more serious inconsistencies with current best practices for conducting contingent valuation studies. As such, EPA does not conclude that the McClelland study provides a useful value for residential visibility changes in both the low and high ends of the benefits estimates. Instead, residential visibility values are included only in the high end estimate of total benefits. EPA does not quantify the value of residential visibility changes in the low end estimate of total benefits. However, EPA recognizes that residential visibility is likely to have some value, thus the low end estimate of total visibility benefits is likely to be an underestimate.

Visibility effects as described in Chapter 3 are measured in terms of changes in deciview, a unitless measure useful for comparing the effects of air quality on visibility. This measure is directly related to two other common visibility measures: visual range (measured in km) and light extinction (measured in km^{-1}). Modeled changes in visibility are measured in terms of changes in light extinction, which are then transformed into deciviews[1]. A change of one deciview represents a change of approximately 10 percent in the light extinction budget, "which is a small but perceptible scenic change under many circumstances." (Sisler, 1996) A change of less than 10 percent in the light extinction budget represents a measurable improvement in visibility, but may not be perceptible to the eye in many cases. Some of the average regional changes in visibility are less than one deciview (i.e. less than 10% of the light extinction budget), and thus less than perceptible. However, this does not mean that these changes are not real or significant. Our assumption is then that individuals can place values on changes in visibility that may not be perceptible. This is quite plausible if individuals are aware that many regulations lead to small improvements in visibility which when considered together amount to perceptible changes in visibility.

Visibility is a function of the ability of gases and aerosols to scatter and absorb light. In the 1997 PM and Ozone NAAQS RIA and the NOx State implementation plan (SIP) call RIA, when calculating residential visibility, the S-R matrix estimate included terms for sulfates, nitrates and coarse PM, but did not include organic matter and other variables. By not including these other terms, the resulting estimates of WTP for residential and recreational visibility improvement were initially overestimated and had to be adjusted to obtain correct residential visibility benefit estimates. Advances in modeling have occurred since then, such that the full extinction budget is now modeled for all counties in the U.S., as mentioned in Chapter 4. Thus, no adjustments to the S-R matrix outputs are necessary to obtain correct visibility benefits. For more details, refer to the control measures technical support document (U.S. EPA, 1999b).

The general approach to estimating the benefit of visibility improvements is based on standard microeconomic theory, which holds that the value of an environmental quality improvement is simply the sum of the amounts that individuals would be willing to pay for it. We estimated each household's WTP for all visibility improvements – both the residential visibility improvement near the household and the visibility improvements at the 156 Federal Class I Areas around the country. The total benefit of all changes in visibility is then calculated as the sum of these household WTPs. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (1999).

To estimate a household's WTP for visibility improvements at federal Class I areas, i.e. national parks and wilderness areas ("recreational visibility") and in the household's local area ("residential visibility"), we assumed that both kinds of visibility improvements result in utility for

[1] See Chapter 3 for a more complete discussion of the deciview and its relation to light extinction.

the household; both kinds of visibility are therefore arguments in the household's utility function[2], i.e.,

$$U = U\left(X,\ Z,\ Q_{IN},\ Q_{OUT}\right),$$

where X represents all non-visibility consumption goods, Z is the level of visibility in the household's local area (within a county, for example), Q_{IN} is the set of visibility levels at Class I parks in the household's region, and Q_{OUT} is the set of visibility levels at Class I parks outside of the household's region. Once the utility function is specified and the parameters of the utility function are estimated, WTP for any set of improvements in residential and recreational visibility can be calculated.

Changes in visibility due to changes in particulate matter were measured in terms of extinction coefficients, converted into deciviews. The deciview is a measure of the *lack* of visibility, and is therefore an "environmental bad," i.e., higher values result in lower utility. However, under a fixed set of "average" atmospheric conditions, a relationship can be defined between the reduction in deciviews from a baseline level to a lower level and the resulting increase in visibility, measured in terms of visual range. Thus, we can obtain measures of Z, Q_{IN}, and Q_{OUT} as functions of the corresponding deciview levels. By incorporating these functions into the utility function, we can calculate the increase in visibility (and the corresponding increase in utility) that would result from a reduction from a given baseline level to some lower level of the "environmental bad." The chain is as follows: a given reduction in deciview (the "bad") results in a given increase in visual range (the "good"), which in turn results in a given increase in utility. Given a specification for the utility function, we can then calculate the WTP for the increase in visibility.

For this analysis, we selected a Constant Elasticity of Substitution (CES) utility function, in which utility is a function of "all consumption goods," and the three categories of visibility (in-region recreational, out-of-region recreational, and residential visibility)[3]. The CES utility

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[2] Economists use the utility function as a convenient mathematical representation of a consumer's preferences for consumption goods, environmental quality and other quality of life factors. Economists assume that consumers make choices between consumption goods (and quality of life levels) to maximize the level of utility they can achieve for a given level of income. The value expressed by a utility function (often referred to as the level of "utils") has no intrinsic meaning, merely serving as an index of the level of satisfaction a consumer achieves given a set of consumption and quality of life levels.

[3] The CES utility function for a household in the nth residential area and the ith region of the country is specified as $U_{ni} = (X^\rho + \theta Z_n^\rho + \sum_{k=1}^{N_i} \gamma_{ik} Q_{ik}^\rho + \sum_{j\neq i} \sum_{k=1}^{N_j} \delta_{jk} Q_{jk}^\rho)^{1/\rho} \quad , \theta > 0, \gamma_{ik} > 0, \forall i, k, \delta_{jk} > 0, \forall j, k,\ \rho \leq 0.$, where Z_n = the level of

function is a very simple utility function, employed here primarily because it yields tractable WTP functions. Alternative assumptions about the form of the utility function may yield different estimates of WTP. Because visibility is not a marketed good, and therefore does not have a market price, the household's maximum achievable utility is a function of household income, each of the two categories of recreational visibility, and residential visibility. The WTP for a change in visibility in any of the three categories can be derived from the CES utility function. Holding all other visibility levels constant, the specification for WTP for a recreational visibility for the kth park in a household's region i is derived from the CES utility function is

$$WTP(\Delta Q_{ik}) = m - \left[m^{\rho} + \gamma_{ik}\left(Q_{0ik}^{\rho} - Q_{1ik}^{\rho}\right)\right]^{\frac{1}{\rho}}$$

where m is household income, Q_0 is the baseline visibility level and Q_1 is the improved visibility level. The specifications for WTP for changes in visibility in out-of-region parks and in residential visibility are similar, with appropriate substitutions for the Q's.

This formulation allows the household's WTP for visibility improvements to depend on household income. The CES utility function described above has several parameters, one of which (the "shape" parameter, ρ) is closely related to the elasticity of substitution. In addition for applications where the WTP is a small share of income, ρ is approximated by one minus the income elasticity of WTP. There is some evidence, although limited, that the income elasticity of WTP for visibility improvements is about 0.9 (Chestnut, 1997). Because the evidence suggests that the income elasticity is about 0.9, we set the shape parameter to 0.1 (if WTP were not affected by income, the income elasticity of WTP would be zero and the shape parameter would be 1). Thus, the WTP specification we employ is consistent with an income elasticity that is different from zero.

In addition to allowing WTP to depend on income, the above specification of WTP also allows WTP to be a decreasing function of the baseline visibility level. The WTP function thus has commonly observed economic properties, i.e., it is an increasing function of income and a decreasing function of the environmental good, reflecting decreasing marginal utility.

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visibility in the nth residential area; Q_{ik} = the level of visibility at the kth in-region park (i.e., the kth park in the ith region); Q_{jk} = the level of visibility at the kth park in the jth region (for which the household is out-of-region), $j \neq i$; N_i =the number of parks in the ith region; N_j =the number of parks in the jth region (for which the household is out-of-region), $j \neq i$; and θ, the γ's and δ's are parameters of the utility function corresponding to the visibility levels at residential areas, and at in-region and out-of-region parks, respectively.

The other parameters (θ and the γ's and δ's mentioned in footnote 1) correspond to each of the visibility arguments in the utility function. Each of these parameters can be estimated if we assume that the corresponding visibility category is the first in the set of visibility categories to be valued by the household.[4] To estimate these parameters, we relied on several studies in which household WTPs for visibility improvements were estimated. The basic approach was to calibrate each parameter to the information in the appropriate study. For example, McClelland et al. (1991) estimated household WTP for a specific improvement in residential visibility. Using the mean income and the mean WTP for the specified visibility change reported in the study, and assuming a value of 0.1 for the "shape" parameter (ρ) in the CES utility function, we calibrated the value of the "residential visibility" parameter (θ) to the McClelland et al. study. We calculated the value of the "residential visibility" parameter (θ) that would result in a WTP for a change from the baseline to the improved visibility level in the study equal to the mean WTP reported in the study. The same method was used to estimate each of the recreational visibility category parameters (γ's and δ's).

While the residential visibility parameter was assumed to be the same for households everywhere (due to the limited geographical scope of the McLelland, et al. study), the recreational visibility parameters depend on the household's location. The WTP for improvements in recreational visibility is based on the results of a 1990 Cooperative Agreement project jointly funded by the EPA and the National Park Service (NPS), "Preservation Values For Visibility Protection at the National Parks." Based on the results of this study Chestnut and Rowe, 1990, estimated WTP (per household) for visibility changes at national parks in several areas of the United States – both for households that are in-region (in the same region as the park) and for households that are out-of-region. The areas for which in-region and out-of-region WTP estimates are available, and the sources of benefit transfer-based estimates that we employed in the absence of direct estimates, are summarized in Table 1 below. In all cases, WTP refers to WTP per household.

[4] The order in which the household considers its WTP for each of a series of environmental quality improvements will affect its WTP for each improvement, although it will not affect the total WTP for the entire series of improvements. This is because each WTP depends on the household's income, which is diminished by what it has already paid for previous environmental quality improvements. Because household WTP for visibility improvements is generally a very small proportion of total household income, however, the impact of the order of consideration of WTP on the WTP for each individual visibility improvement will be negligible. For more details on this issue see the benefits TSD for this RIA (Abt Associates, 1999).

Table 9-4

Available Information on WTP for Visibility Improvements in National Parks

Region of Park[a]	**Region of Household**	
	In-Region[b]	**Out-of-Region**[c]
1. California	WTP estimate from Chestnut and Rowe, 1990	WTP estimate from Chestnut and Rowe, 1990
2. Colorado Plateau (Southwest)	WTP estimate from Chestnut and Rowe, 1990	WTP estimate from Chestnut and Rowe, 1990
3. Southeast United States	WTP estimate from Chestnut and Rowe, 1990	WTP estimate from Chestnut and Rowe, 1990
4. Northwest United States	(based on benefits transfer from California)	
5. Northern Rockies	(based on benefits transfer from Colorado Plateau)	
6. Rest of United States	(based on benefits transfer from Southeast U.S.)	

[a] Transfer regions are groups of states adjacent to the study region from which WTP values are assigned and which were subjectively determined to have broadly similar park characteristics. Transfer regions include Northwest U.S. (Oregon and Washington), Northern Rockies (Idaho, Montana, and Wyoming), and Rest of U.S.

[b] "In-region" WTP is WTP for a visibility improvement in a park in the same region as that in which the household is located. For example, in-region WTP in the "California" row is the estimate of the average California household's WTP for a visibility improvement in a California park.

[c] "Out-of-region" WTP is WTP for a visibility improvement in a park that is not in the same region in which the household is located. For example, out-of-region WTP in the "California" row is the estimate of WTP for a visibility improvement in a park in California by a household outside of California.

While the CV studies are "park-specific," the utility functions are "household-specific." The values of the parameters in a household's utility function will depend on where the household is located. For households in a region in which a study was conducted (i.e., California, the Colorado Plateau, or the Southeast United States), we directly use the "in-region" WTP estimate from the study to estimate the parameters in the utility function corresponding to visibility at in-region parks. Similarly, we directly use the "out-of-region" WTP estimates from the studies to estimate the corresponding parameters for out-of-region households. For example, the parameters in the utility function of a household in Minnesota corresponding to visibility improvements at California parks are derived using the study estimate of out-of-region WTP for visibility improvements at California parks.

To estimate these parameters for visibility at parks in regions for which no study has been conducted, we relied on benefits transfers, as outlined in Table 9-4. A visibility improvement in parks in one region, however, is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference in environmental quality goods being valued into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions[5]. Suppose, for example, that WTP for a change in visibility at California parks from level Q_0 to level Q_1 was estimated to be $WTP. Suppose, in addition, that California parks are visited twice as often per year as parks in the Northwest. Then the WTP for a visibility change in Northwest parks from level Q_0 to level Q_1 would be calculated as 0.5*$WTP. This WTP estimate would then be used to calculate the parameters for visibility at Northwest parks in the same way that the original WTP estimate for California was used to calculate parameters for visibility at California parks.

The Chestnut and Rowe (1990) study which estimated WTP for recreational visibility improvements at parks in a region did not estimate park-specific WTPs, but only WTP for the improvement at "parks in the region." Region-wide WTPs were therefore apportioned to specific parks within the region. Each park-specific value was calculated as the region-wide WTP times that park's share of total visits per year in the region. However, the WTP function parameters at all parks within a region are determined by the WTP reported for the entire region.

The Preservation Values study examined the demand for visibility in Class I-areas managed by the National Park Service in three broad regions of the country, California, Southwest, and Southeast[6]. For a given region, the Preservation Values study asked respondents in Arizona, California, Missouri, New York and Virginia for their willingness to pay to protect visibility at National Parks (or wilderness areas managed by the NPS) in that region. Table 9-5 lists the parks included in the study. The RH rule is a national program which should have impacts on visibility in Class I areas throughout the entire U.S. and including both National Parks and Federal Wilderness Areas managed by the NPS, Forest Service (FS), and Fish and Wildlife Service (FWS). In the proposed RH Rule (1997), visibility changes outside of the three study

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[5] This assumes that differences in preferences for visibility at different parks can be proxied for by observed visitation behavior. This is clearly a very crude approximation, since the WTP we are estimating includes both use and non-use values, and a visitation rate is a better measure of use value and is not clearly linked to non-use values. However, short of conducting surveys for individual parks, it is difficult to estimate the relative importance of visibility at each park, so visitation rates may provide a reasonable proxy relative to other types of park information, such as park size.

[6] Chestnut and Rowe classified any national park or wilderness area as a Class I national park if the park or wilderness area was under management by the National Park Service. For the purposes of this discussion and our analysis, a wilderness area is defined as any Class I area under the management of the Forest Service or Fish and Wildlife Services.

regions examined in the Preservation Values study were not assigned any monetary value. In addition, non-NPS Class I areas within study regions were not assigned any monetary value. Given the large changes in visibility occurring in regions outside of the set of Preservation Values study regions, the method used in the proposal severely understated the potential monetary value of visibility changes from the RH rule. To address this deficiency, this analysis uses benefit transfer methods to derive monetary benefits for visibility changes in Class I areas outside of the Preservation Values study regions and for non-NPS Class I areas within the study regions. A full list of the 147 Class I areas and associated park visitation rates is available in Appendix F to this RIA.

Transference of WTP values from the Chestnut and Rowe study regions to non-NPS Class I areas outside the study areas is accomplished in the same manner as for NPS Class I areas outside the study regions. Transference of WTP values to wilderness areas within the study regions can be accomplished in two different ways, depending on the assumed nature of the WTP responses. Recall that respondents were asked their WTP for a visibility changes at all NPS managed Class I areas in a region. Prior to the question, respondents were provided with a map showing the locations of the NPS managed Class I areas in each region. This map did not show the location or number of other Class I areas (managed by the Forest Service or Fish and Wildlife Service) in each region. The first method for transferring WTP to non-NPS Class I areas is to assume that respondents did not include these areas in their WTP for visibility changes in the region. If this is the case, then these areas can be treated the same as other transfer areas. The second method for transferring WTP to non-NPS Class I areas is to assume that respondents did include the non-NPS Class I areas in their WTP for visibility changes in the region, i.e., WTP for visibility changes in non-NPS areas is embedded in the WTP for visibility changes in the entire region. If this is the case, then the WTP for visibility changes in the non-NPS area should be a portion of the WTP for the entire region. If the first method is assumed, then the total WTP for visibility changes at all Class I areas in a study region will exceed the WTP reported in the Chestnut and Rowe study. If the second method is assumed, then the total WTP for visibility changes at all Class I areas in a study region will equal the WTP reported in the Chestnut and Rowe study, but the WTP for a given Class I area in the region will be lower than if the non-NPS areas were excluded. For this analysis, we use the first method to generate the high estimate of visibility benefits for non-NPS Class I areas and the second method to generate the low-end estimate of visibility benefits for non-NPS Class I areas.

Table 9-5

Class I Areas Included in Visibility Study By Region

Visibility Region	National Parks
California	**Yosemite**, Sequoia/Kings Canyon, Redwoods, Pinnacles, Lava Beds, Death Valley, Lassen Volcanic, Joshua Tree, Point Reyes
Southwest	**Grand Canyon**, Mesa Verde, Arches, Bandelier, Capitol Reef, Carlsbad Caverns, Bryce Canyon, Chiricahua, Zion, Saguaro, Canyonlands, Petrified Forest, Rocky Mountain
Southeast	**Shenandoah**, Great Smoky Mountains, Mammoth Cave, Everglades

Note: The "indicator" park is shown in bold for each of these three regions. In each case the indicator park is a well-known park in that region. Source: Chestnut (1997).

Photos from each of the study regions' "indicator parks" were provided as part of the survey instrument. After a number of preparatory questions, respondents reached the WTP section of the survey. Respondents were first instructed that their answer to the WTP question applied only to the region in their survey, and that they did not have to worry about other regions of the country. This makes it less likely that there will be overlap between residential and recreational visibility benefits.

The in-region coefficient estimates the WTP of residents within a given visibility region for visibility improvements at all parks located within that same region. The out-of-region coefficient estimates the WTP of residents living outside a given visibility region for visibility improvements at all parks located within that region. The results of the survey suggest that in-region residents are likely to value visibility improvements at their parks more than out-of-region residents. This is consistent with expectations, as in-region households are more likely to visit, know about, and care for these parks.

Total visibility benefits consist of a combination of residential, in-region and out-of-region recreational visibility benefits. Because of the substantial uncertainty about the reliability of the WTP values estimated in the McLelland, et al. residential visibility study, residential visibility values are not included in the low-end estimate of total visibility benefits. The low-end estimate of total visibility benefits is thus equal to just the in-region and out-of-region recreational visibility values for Class I areas, assuming that the WTP for visibility changes at non-NPS Class I areas is included in the total WTP for visibility changes at NPS Class I areas in a region. In the high-end estimates, total visibility benefits consist of residential visibility benefits, as well as in- and out-of-region recreational visibility benefits for Class I areas, assuming that WTP for non-

NPS Class I areas is in addition to the total WTP for visibility changes at NPS Class I areas in a region.

9.5 Monetized PM-Related Health and Welfare Benefits

Although the primary environmental purpose of the RH rule is to help improve visibility in federal Class I areas, significant monetary benefits will also be associated with changes in ambient levels of PM. While a broad range of adverse health and welfare effects have been associated with exposure to elevated PM levels, only subsets of these effects are selected for inclusion in the quantified benefit analysis. Effects are excluded from the current analysis(1) in order to prevent double counting (such as hospital admissions for specific respiratory diseases); (2) due to uncertainties in applying effect relationships based on clinical studies (where human subjects are exposed to various levels of air pollution in a carefully controlled and monitored laboratory situation) to the population affected by the RH rule; or (3) due to a lack of an established concentration-response relationship. The PM-related effect categories that are included in this analysis are shown in Tables 9-6 and 9-7. For all of the PM-related health endpoints, benefits are estimated under three threshold assumptions: background, lowest observed level in the study from which the concentration-response function is taken, and 15 $\mu g/m^3$, the current PM standard.

The general format for the following sections detailing the benefit assessment methodology for each endpoint is to begin with a presentation of the study used to obtain the concentration-response function for estimation of avoided incidences and then present the method and studies used for economic valuation. For additional information about specific endpoints, see the technical support document for this RIA (Abt Associates, 1999).

Table 9-6

Quantified PM-Related Health Effects Included in the Benefits Analysis

Endpoint	Population to Which Applied	Study
Mortality		
$PM_{2.5}$-related long-term exposure mortality	ages 30+	Pope et al., 1995
Hospital Admissions		
"all respiratory"	all ages	Thurston et al., 1994
Congestive heart failure	age 65+	Schwartz and Morris, 1995
Ischemic heart disease	age 65+	Schwartz and Morris, 1995
Chronic Bronchitis		
Development of chronic bronchitis	all	Schwartz, 1993
Respiratory Symptoms/Illnesses Not Requiring Hospitalization		
Acute bronchitis	ages 10-12	Dockery et al., 1989
$PM_{2.5}$-related lower respiratory symptoms (LRS)	ages 8-12	Schwartz et al., 1994
Upper respiratory symptoms (URS)	asthmatics, age 9-11	Pope et al., 1991
MRADs	ages 18-65	Ostro and Rothschild, 1989
Work loss days (WLDs)	ages 18-65	Ostro, 1987

Table 9-7

Quantified PM-Related Welfare Effects Included in the Benefits Analysis

Endpoint	Population to Which Applied	Study
Household Soiling	all households	Manuel, et al in ESEERCO, 1994
Nitrogen Deposition to Eastern Estuaries[a]	nitrogen sensitive estuaries	EPA, 1999c

[a] Nitrogen deposition is not a PM-related benefit, but rather is a direct result of emissions of NOx. However, for convenience of presentation, it is included in the set of PM-related benefits.

9.5.1 Issues in Estimating Changes in Health Effects

This benefits analysis relies on concentration-response (C-R) functions estimated in published epidemiological studies relating adverse health and welfare effects to ambient air quality. The specific C-R functions used are included in Table 9-8.

When a single published study is selected as the basis of the C-R relationship between a pollutant and a given health endpoint, applying the C-R function is straightforward. This is the case for the endpoints selected for inclusion in the benefits analysis. A single C-R function may be chosen over other potential functions because the underlying epidemiological study used superior methods, data or techniques, or because the C-R function is more generalized and comprehensive. For example, the study that estimated the effects of PM on hospital admissions for all ages and all respiratory diseases is selected over studies limited to the over 65 year old population or specific categories of respiratory diseases.

The same concentration-response relationship is applied everywhere in the benefits analysis. Although the concentration-response relationship may in fact vary somewhat from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific concentration-response functions are generally not available. While a single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates of incidence changes in other locations, these location-specific biases will to some extent cancel each other out when the total incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on application of a single C-R function everywhere.

The remainder of this section discusses two key issues involving the use of C-R functions to estimate the benefits of the RH rule: baseline incidences and health effect thresholds, i.e., levels of pollution below which changes in air quality have no impacts on health.

9.5.1.1 Baseline Incidences

The epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the relative risk of a health effect, rather than an estimate of the absolute number of avoided cases. For example, a typical result might be that a 10 $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases.

United States county-level baseline mortality rates for 1990 were obtained from the National Center for Health Statistics (US Department of Health and Human Services, 1994). Because most PM studies that estimate C-R functions for mortality considered only non-accidental mortality, county-specific baseline mortality rates used in the estimation of PM-related mortality were adjusted to provide a better estimate of county-specific non-accidental mortality. Each county-specific mortality rate was multiplied by the ratio of national non-accidental mortality to national total mortality (0.93).

Although total mortality incidences (over all ages) are available for counties, age-specific mortality incidences is not generally available at the county level. Therefore, county-specific baseline mortality incidences among individuals aged 30 and over (necessary for $PM_{2.5}$-related long-term exposure mortality, estimated by Pope et al., 1995) are estimated by applying national age-specific death rates to county-specific age distributions, and adjusting the resulting estimated age-specific incidences so that the estimated total incidences (including all ages) equals the actual county-specific total incidences.

Unlike mortality, county-specific baseline incidence rates for morbidity endpoints are not available. When available, national baseline incidences of these endpoints are used to estimate the county-specific rates. If the C-R function for the health effect is limited to a certain age group (such as ages 65 and older), the county-specific baseline incidence rate is estimated by multiplying the national all-age baseline incidence rate by the ratio of the county-specific proportion of the population in the relevant age group to the national proportion of the population in the relevant age group.

Baseline incidence rates for all respiratory symptoms and illnesses included in the benefit analysis and for restricted activity days are obtained from the studies reporting C-R functions for those health endpoints. No baseline incidence rates are available from other sources for these endpoints.

Table 9-8

PM Health and Welfare Concentration-Response Function Summary Data

Endpoint	Pollutant	Concentration-Response Function		Averaging Time		Population[a]	Pollutant Coefficient[b]
		Source	Functional Form	Studied	Applied		
Mortality							
Mortality (long-term exposure) -$PM_{2.5}$	$PM_{2.5}$	Pope et al., 1995	log-linear	annual median	annual median[c]	ages 30+	0.006408
Hospital Admissions							
All respiratory illnesses	$PM_{2.5}$/ PM_{10}	Thurston et al., 1994	linear	1-day average	1-day average	all	3.45×10^{-8}
Congestive heart failure	PM_{10}	Schwartz & Morris, 1995	log-linear	2-day average	1-day average	age 65+	0.00098
Ischemic heart disease	PM_{10}	Schwartz & Morris, 1995	log-linear	1-day average	1-day average	age 65+	0.00056
Respiratory Symptoms/Illnesses not requiring hospitalization							
Development of chronic bronchitis	PM_{10}	Schwartz, 1993		annual mean	annual mean	all	0.012
Acute bronchitis	$PM_{2.5}$/ PM_{10}	Dockery et al., 1989	logistic	annual mean	annual mean[d]	ages 10-12	0.0298
Upper respiratory symptoms (URS)	PM_{10}	Pope et al., 1991	log-linear	1-day average	1-day average	asthmatics, ages 9-11	0.0036
Lower respiratory symptoms (LRS)	PM_{10}	Schwartz et al., 1994	logistic	1-day average	1-day average	ages 8-12	0.01823

Endpoint	Pollutant	Concentration-Response Function		Averaging Time		Population[a]	Pollutant Coefficient[b]
		Source	Functional Form	Studied	Applied		
Minor Restricted Activity Days (MRADs)	$PM_{2.5}$	Ostro and Rothschild, 1989	log-linear	2-week average	1-day average	ages 18-65	0.00741
Work loss days (WLDs)	$PM_{2.5}$	Ostro, 1987	log-linear	2-week average	1-day average	ages 18-65	0.0046
Welfare Endpoints							
Household soiling and damage	PM_{10}	ESEERCO, 1994	linear	annual mean	annual mean	all households	2.52 (dollars per µg/ m^3 PM10 per household)

[a] The population examined in the study and to which this analysis applies the reported concentration-response relationship. In general, epidemiological studies analyzed the concentration-response relationship for a specific age group (e.g., ages 65+) in a specific geographical area. This analysis applies the reported pollutant coefficient to all individuals in the age group nationwide.

[b] A single pollutant coefficient reported for several studies indicates a pooled analysis; see text for discussion of pooling concentration-response relationships across studies.

[c] All 1-day averages are 24-hour averages, 2-day averages are 48-hour averages, etc.

9.5.1.2 Thresholds

A very important issue in applied modeling of changes in PM is whether to apply the concentration-response functions to all predicted changes in ambient concentrations, even small changes occurring at levels approaching "anthropogenic background". Different assumptions about how to model thresholds can have a major effect on the resulting benefits estimates.

The underlying epidemiological functions used in most of this analysis are in fact continuous down to zero levels. However, in order to remain consistent with the available scientific information, the health benefits estimates for the analysis do not model effects below certain levels. The approach used in the analysis is to provide estimates of benefits under two assumptions, 1) individual concentration-response functions will not be applied to ambient concentrations occurring below the current PM2.5 standard of 15 15 $\mu g/m^3$ and 2) individual concentration-response functions will be applied to ambient concentrations occurring down to the "anthropogenic background" level.

Theoretically, C-R functions should be reestimated when a threshold is assumed to insure consistency with the observed correlation between mortality incidences and the pollutant. If no threshold is assumed in the epidemiological study, then the slope of the C-R function will be flatter than for a function with a threshold. This reflects the fact that all of the observed changes in mortality would have to be associated with changes above the threshold, rather than being associated with changes along the full spectrum of pollutant concentrations. Unadjusted C-R functions are used in this benefits analysis due to a lack of availability of the underlying data used to estimate the C-R functions. These data are necessary to develop threshold adjusted C-R functions. Use of an unadjusted C-R function will result in an underestimate of total avoided incidences when a threshold is assumed.

9.5.2 Premature Mortality

Particulate matter has been associated with increased risk of premature mortality in adult populations (Pope, et al., 1995). Avoided mortality is a very important health endpoint in this economic analysis due to the high monetary value associated with risks to life.

9.5.2.1 *Measuring Reductions in Premature Mortality Risk*

The PM-related premature mortality in the benefits analysis is estimated using the $PM_{2.5}$ relationship from Pope et al., 1995. This decision reflects the Science Advisory Board's explicit recommendation for modeling the mortality effects of PM in both the completed §812

Retrospective Report to Congress and the ongoing §812 Prospective Study. The Pope study estimates the association between long-term (chronic) exposure to $PM_{2.5}$ and the survival of members of a large study population. This relationship is selected for use in the benefits analysis instead of short-term (daily pollution) studies for a number of reasons outlined below.

There are two types of exposure to elevated levels of PM that may result in premature mortality. Acute (short-term) exposure (e.g., exposure on a given day) to peak PM concentrations may result in excess mortality on the same day or within a few days of the elevated PM exposure. Chronic (long-term) exposure (e.g., exposure over a period of a year or more) to levels of PM that are generally higher may result in mortality in excess of what it would be if PM levels were generally lower. The excess mortality that occurs will not necessarily be associated with any particular episode of elevated air pollution levels. Both types of effects are biologically plausible, and there is an increasing body of consistent corroborating evidence from animal toxicity studies indicating that both types of effects exist.

There are, similarly, two basic types of epidemiological studies of the relationship between mortality and exposure to PM. Long-term studies (e.g., Pope et al., 1995) estimate the association between long-term (chronic) exposure to PM and the survival of members of a large study population over an extended period of time. Such studies examine the health endpoint of concern in relation to the general long-term level of the pollutant of concern -- for example, relating annual mortality to some measure of annual pollutant level. Daily peak concentrations would impact the results only insofar as they affect the measure of long-term (e.g., annual) pollutant concentration. In contrast, short-term studies relate daily levels of the pollutant to daily mortality. By their basic design, daily studies can detect acute effects but cannot detect the effects of long-term exposures. A chronic exposure study design (a prospective cohort study, such as the Pope study) is best able to identify the long-term exposure effects, and will likely detect some of the short-term exposure effects as well. Because a long-term exposure study may detect some of the same short-term exposure effects detected by short-term studies, including both types of study in a benefit analysis would likely result in some degree of double counting of benefits.

Another major advantage of the long-term study design concerns the issue of the degree of prematurity of mortality associated with PM. It is possible that the short-term studies are detecting an association between PM and mortality that is primarily occurring among terminally ill people. Critics of the use of short-term studies for policy analysis purposes correctly point out that an added risk factor that results in a terminally ill person dying a few days or weeks earlier than they otherwise would have (known as “short-term harvesting”) is potentially included in the measured PM mortality “signal” detected in such a study. As the short-term study design does not examine individual people (it examines daily mortality rates in large populations, typically a large city population), it is impossible to know anything about the overall health status of the specific population that is detected as dying early. While some of the detected excess deaths may have resulted in a substantial loss of life (measuring loss of life in terms of lost years of remaining life), others may have lost a relatively short amount of life span.

It is much less likely that the excess mortality reported by Pope et al., 1995, whose study is based on a prospective cohort design, contains any significant amount of this short-term harvesting. First, the health status of each individual tracked in the study is known at the beginning of the study period. Persons with known pre-existing serious illnesses were excluded from the study population. Second, the Cox proportional hazard statistical model used in the Pope study examines the question of survivability throughout the study period (10 years). Deaths that are premature by only a few days or weeks within the 10-year study period (for example, the deaths of terminally ill patients, triggered by a short duration PM episode) are likely to have little impact on the calculation of the average probability of surviving the entire 10 year interval.

The Pope long-term study is selected as providing the best available estimate of the relationship between PM and mortality. It is used alone, rather than considering the total effect to be the sum of estimated short-term and long-term effects, because summing creates the possibility of double-counting a portion of total mortality. The Pope study is selected in preference to other available long-term studies because it uses the best methods (i.e., a prospective cohort method with a Cox proportional hazard model), and has a much larger cohort population, the longest exposure interval, and more locations (51 cities) in the United States, than other studies. In relation to the other prospective cohort study (Dockery, et al., 1992, the "Six-cities" cohort study), the Pope study found a smaller increase in excess mortality for a given PM air quality change.

9.5.2.2 *Valuing Reductions in Premature Mortality Risk*

The benefits analysis uses two approaches to determining the value of an avoided statistical incidence of premature mortality, the value of a statistical life (VSL) and the value of a statistical life year (VSLY). The high-end estimate uses the "statistical lives lost" approach to value avoided premature mortality. The mean value of avoiding one statistical death (VSL) is estimated to be $4.8 million. This represents an intermediate value from a variety of estimates that appear in the economics literature, and is a value that EPA has frequently used in RIAs for other rules. This estimate is the mean of a fitted Weibull distribution of the estimates from 26 value-of-life studies identified in the §812 study as "applicable to policy analysis." The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria used by Viscusi in his review of value-of-life studies. The $4.8 million estimate is consistent with Viscusi's conclusion that "most of the reasonable estimates of the value of life are clustered in the $3 to $7 million range." Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs. The 26 studies used to form the distribution of the VSL are listed in Table 9-9. A full set of references for the 26 studies can be found in Viscusi (1992).

The low-end estimate of the value of an avoided incidence of premature mortality is developed using the "statistical life-years lost" approach. If life-years lost is the measure used, then the value of a statistical life-year lost, rather than the value of a statistical life lost would be needed. Moore and Viscusi (1988) suggest one approach for determining the VSL-year lost. They assume that the willingness to pay to save a statistical life is the value of a single year of life times the expected number of years of life remaining for an individual. They suggest that a typical respondent in a mortal risk study may have a life expectancy of an additional 35 years. Using a mean estimate of $4.8 million to save a statistical life, their approach would yield an estimate of $137,000 per life-year lost or saved. If an individual discounts future additional years using a positive discount rate, the value of each life-year lost must be greater than the value assuming no discounting or a zero rate. Using a 35-year life expectancy, a $4.8 million value of a statistical life, and a 5 percent discount rate, the implied value of each life-year lost is $293,000. The value used in the RH benefits analysis will be calculated using the discount rate assumptions adopted for the entire analysis. A higher discount rate will produce a greater value per life-year, and a lower discount rate will produce a lower value. The Moore and Viscusi procedure is identical to this approach, but uses a zero discount rate. In addition to the VSLY, the expected number of life-years saved is necessary to determine the appropriate value for an avoided incidence of premature mortality. Based on adjustments to reflect age-specific relative risks developed in the §812 study, the average number of life-years lost due to PM related premature mortality is determined to be 9.8 years. Using the $4.8 million value of a statistical life (equivalent to 35 years of life), a 5% discount rate, and average life-years lost equal to 9.8 years, the value of an avoided incidence of PM-related premature mortality is then $2.2 million.

Table 9-9
Summary of Mortality Valuation Estimates from Viscusi (1992)

Study	Type of Estimate	Valuation per Statistical Life (millions of 1990 $)
Kneisner and Leeth (1991) (U.S.)	Labor Market	0.6
Smith and Gilbert (1984)	Labor Market	0.7
Dillingham (1985)	Labor Market	0.9
Butler (1983)	Labor Market	1.1
Miller and Guria (1991)	Contingent Valuation	1.2
Moore and Viscusi (1988a)	Labor Market	2.5
Viscusi, Magat, and Huber (1991b)	Contingent Valuation	2.7
Gegax et al. (1985)	Contingent Valuation	3.3
Marin and Psacharopoulos (1982)	Labor Market	2.8
Kneisner and Leeth (1991) (Australia)	Labor Market	3.3
Gerking, de Haan, and Schulze (1988)	Contingent Valuation	3.4
Cousineau, Lacroix, and Girard (1988)	Labor Market	3.6
Jones-Lee (1989)	Contingent Valuation	3.8
Dillingham (1985)	Labor Market	3.9
Viscusi (1978, 1979)	Labor Market	4.1
R.S Smith (1976)	Labor Market	4.6
V.K. Smith (1976)	Labor Market	4.7
Olson (1981)	Labor Market	5.2
Viscusi (1981)	Labor Market	6.5
R.S. Smith (1974)	Labor Market	7.2
Moore and Viscusi (1988a)	Labor Market	7.3
Kneisner and Leeth (1991) (Japan)	Labor Market	7.6
Herzog and Schlottman (1987)	Labor Market	9.1
Leigh and Folson (1984)	Labor Market	9.7
Leigh (1987)	Labor Market	10.4
Gaten (1988)	Labor Market	13.5

9.5.3 Hospital Admissions

The benefits analysis includes three types of PM-related hospital admissions, due to all respiratory illnesses (Thurston et al., 1994), congestive heart failure (Schwartz and Morris, 1995), and ischemic heart disease (Schwartz and Morris, 1995). The benefits analysis relies on a study of all respiratory hospital admissions for all age groups, rather than studies examining the population over 65.

An individual's WTP to avoid a hospital admission will include, at a minimum, the amount of money they pay for medical expenses (i.e., what they pay towards the hospital charge and the associated physician charge) and the loss in earnings. In addition, however, an individual is likely to be willing to pay some amount to avoid the pain and suffering associated with the illness itself. That is, even if they incurred no medical expenses and no loss in earnings, most individuals would still be willing to pay something to avoid the illness.

Because medical expenditures are to a significant extent shared by society, via medical insurance, Medicare, etc., the medical expenditures actually incurred by the individual are likely to be less than the total medical cost to society. The total value to society of an individual's avoidance of hospital admission, then, might be thought of as having two components: (1) the cost of illness (COI) to society, including the total medical costs plus the value of the lost productivity, as well as (2) the individual's WTP to avoid the disutility of the illness itself (e.g., the pain and suffering associated with the illness).

In the absence of estimates of social WTP to avoid hospital admissions for specific illnesses (components 1 plus 2 above), estimates of total COI (component 1) are typically used as conservative (lower bound) estimates. Because these estimates do not include the value of avoiding the disutility of the illness itself (component 2), they are biased downward. Some analyses adjust COI estimates upward by multiplying by an estimate of the ratio of WTP to COI, to better approximate total WTP. Other analyses have avoided making this adjustment because of the possibility of over adjusting -- that is, possibly replacing a known downward bias with an upward bias. The §812 SAB committee has recommended against adjusting the COI estimates upward. While the previous RIAs for PM and ozone, as well as the revised RIA for ozone and PM NAAQS, did adjust the COI estimate upward, the COI values used in the benefits analysis for the NOx SIP call RIA were not adjusted. Consistent with the §812 SAB committee guidance, the RH benefits analysis will not adjust the COI values upward.

The COI estimates used in this RIA include the estimated hospital and physician charges, based on the average length of a hospital stay for the illness, and the estimated opportunity cost of time spent in the hospital. Total estimated COI for a hospital admission for all respiratory illnesses, congestive heart failure, and ischemic heart disease are $9,106, $11,852, and $14,791, respectively. For a more detailed breakdown of the COI estimates, see the technical support document for this analysis (Abt Associates, 1999).

9.5.4 Chronic and Acute Bronchitis

9.5.4.1 *Measuring Reductions in the Risk of Chronic Bronchitis*

There are a limited number of studies that have estimated the impact of air pollution on chronic bronchitis. An important hindrance is the lack of long-term health data and the associated air pollution levels. Schwartz (1993) and Abbey et al.(1993; 1995) provide the evidence that long-term PM exposure gives rise to the development of chronic bronchitis in the U.S. Following the NO_x SIP call analysis (U.S. EPA, 1998), our analysis uses the Schwartz study to develop a C-R function linking PM to chronic bronchitis.

It should be noted that Schwartz used data on the *prevalence* of chronic bronchitis, not its *incidence*. To use Schwartz's study and still estimate the change in incidence, there are at least two possible approaches. The first is to simply assume that it is appropriate to use the baseline *incidence* of chronic bronchitis in a C-R function with the estimated coefficient from Schwartz's study, to directly estimate the change in incidence. The second is to estimate the percentage change in the prevalence rate for chronic bronchitis using the estimated coefficient from Schwartz's study in a C-R function, and then to assume that this percentage change applies to a baseline incidence rate obtained from another source. (That is, if the prevalence declines by 25 percent with a drop in PM, then baseline incidence drops by 25 percent with the same drop in PM.) Our analysis is using the latter approach, and estimates a percentage change in prevalence which is then applied to a baseline incidence rate.

9.5.4.2 *Valuing Reductions in the Risk of Chronic Bronchitis (CB)*

The PM-related CB is the only measured morbidity endpoint that may be expected to last from the initial onset of the illness throughout the rest of the individual's life. The WTP to avoid CB would therefore be expected to incorporate the present discounted value of a potentially long stream of costs (e.g., medical expenditures and lost earnings) and pain and suffering associated with the illness. Two studies, Viscusi et al. (1991) and Krupnick and Cropper (1992), provide estimates of WTP to avoid a case of CB.

The Viscusi, et al. and Krupnick and Cropper studies were experimental studies intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the EPA believes the studies provide reasonable estimates of the WTP for chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values. Because some specific attributes of the studies raise questions about the reliability of the WTP values, we value CB using cost-of-illness (COI) for the low-end estimate of benefits and using WTP for the high-end estimate. However, EPA recognizes that COI estimates of the benefits of reduced chronic bronchitis risk are a lower bound on WTP and thus the low-end estimate of chronic bronchitis related benefits is most likely an underestimate.

The study by Viscusi et al., uses a sample that is larger and more representative of the general population than the study by Krupnick and Cropper (which selects people who have a relative with the disease). The valuation of CB in our analysis is therefore based on the distribution of WTP responses from Viscusi et al. (1991). The WTP to avoid a statistical case of pollution-related CB is derived by starting with the WTP to avoid a severe case of CB, as described by Viscusi et al. (1991), and adjusting it downward to reflect (1) the decrease in severity of a case of pollution-related CB relative to the severe case described in the Viscusi et al. study, and (2) the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (Krupnick et al., 1992) study. The technical support document describes the adjustment procedure in more detail (Abt Associates, 1999). The mean value of the adjusted distribution is $260,000. This is the WTP for CB we used in our benefits analysis.

This WTP estimate is reasonably consistent with full COI estimates derived for CB, using average annual lost earnings and average annual medical expenditures reported by Cropper and Krupnick (1990). Using a 5 percent discount rate and assuming that (1) lost earnings continue until age 65, (2) medical expenditures are incurred until death, and (3) life expectancy is unchanged by CB, the present discounted value of the stream of medical expenditures and lost earnings associated with an average case of CB is estimated to be about $77,000 for a 30 year old, about $58,000 for a 40 year old, about $60,000 for a 50 year old, and about $41,000 for a 60 year old. A WTP estimate would be expected to be greater than a full COI estimate, reflecting the willingness to pay to avoid the pain and suffering associated with the illness. The WTP estimate of $260,000 is from 3.4 times the full COI estimate (for 30 year olds) to 6.3 times the full COI estimate (for 60 year olds). The low-end estimate of benefits from reduced incidences of CB is calculated based on the midpoint of the COI estimates across the range of ages, equal to $59,000 per case.

9.5.4.2 Measuring Reductions in the Risk of Acute Bronchitis

Dockery et al. (1989) is used to estimate the relationship between PM and acute bronchitis. Dockery et al. examined the effects of PM and other pollutants on the reported rates of chronic cough, bronchitis and chest illness, in a study of 5,422 children aged 10 to 12. Bronchitis and chronic cough were both found to be significantly related to PM concentrations.

9.5.4.2 ***Valuing Reductions in the Risk of Acute Bronchitis***

Estimating WTP to avoid a statistical case of acute bronchitis is difficult for several reasons. First, WTP to avoid acute bronchitis itself has not been estimated. Estimation of WTP to avoid this health endpoint therefore must be based on estimates of WTP to avoid symptoms that occur with this illness. Second, a case of acute bronchitis may last more than 1 day, whereas it is a day of avoided symptoms that is typically valued. Finally, the concentration-response function used in the benefit analysis for acute bronchitis (Dockery, et al., 1989) was estimated for children, whereas WTP estimates for those symptoms associated with acute bronchitis were obtained from adults.

With these caveats in mind, a rough estimate of WTP to avoid a case of acute bronchitis was derived as the midpoint of a low and a high estimate. The low estimate ($13.29) is the sum of the midrange values recommended by IEc (IEc, 1994) for two symptoms believed to be associated with acute bronchitis: coughing ($6.29) and chest tightness ($7.00). The high estimate was taken to be twice the value of a minor respiratory restricted activity day ($38.37), or $76.74. The midpoint between the low and high estimates is $45.00. This value was used as the point estimate of Midpoint WTP to avoid a case of acute bronchitis in the benefit analysis.

9.5.5 Acute Respiratory Symptoms

Exposure to PM may result in the occurrence of acute respiratory symptoms in either or both the upper and/or lower respiratory systems. Because the valuation studies used to provide unit values for the two types of respiratory symptoms, both are presented in this section.

9.5.5.1 *Measuring Reductions in the Risk of Upper Respiratory Symptoms (URS)*

The concentration-response function for URS is taken from Pope et al. (1991). Pope et al. describe URS as consisting of one or more of the following symptoms: runny or stuffy nose; wet cough; and burning, aching, or red eyes. The children in the Pope study were asked to record respiratory symptoms in a daily diary, and the daily occurrences of URS and lower respiratory symptoms (LRS), as defined above, were related to daily PM-10 concentrations. Estimates of WTP to avoid a day of symptoms are therefore appropriate measures of benefit.

9.5.5.2 *Valuing Reductions in the Risk of Upper Respiratory Symptoms*

The WTP to avoid a statistical day of URS is based on symptom-specific WTPs to avoid those symptoms identified by Pope et al. as part of the URS complex of symptoms. Three CV studies have estimated WTP to avoid various morbidity symptoms that are either within the URS symptom complex defined by Pope et al. or are similar to those symptoms identified by Pope et al. In each CV study, participants were asked their WTP to avoid a day of each of several symptoms. The three individual symptoms that were identified as most closely matching those listed by Pope et al. for URS are cough, head/sinus congestion, and eye irritation. A day of URS could consist of any one of seven possible "symptom complexes" consisting of at least one of these symptoms. It is assumed that each of the seven types of URS is equally likely. The *ex ante* MWTP to avoid a day of URS is therefore the average of the MWTPs to avoid each type of URS, or $18.70. This is the point estimate for the dollar value for URS used in the benefit analysis. Finally, it is worth emphasizing that what is being valued here is URS *as defined by Pope et al., 1991*. While other definitions of URS are certainly possible, this definition of URS is used in this benefit analysis because it is the incidence of this specific definition of URS that has been related to PM exposure by Pope et al., 1991.

9.5.5.3 Measuring Reductions in the Risk of Lower Respiratory Symptoms

Schwartz et al. (1994) is used to estimate the relationship between LRS and PM-10 concentrations. Schwartz et al. (1994) define LRS as at least two of the following symptoms: cough, chest pain, phlegm, and wheeze. The symptoms for which WTP estimates are available that reasonably match those listed by Schwartz et al. for LRS are cough (C), chest tightness (CT), coughing up phlegm (CP), and wheeze (W). A day of LRS, as defined by Schwartz et al., could consist of any one of the eleven combinations of at least two of these four symptoms.

9.5.5.4 *Valuing Reductions in the Risk of Lower Respiratory Symptoms*

It is assumed that each of the eleven types of LRS is equally likely. The *ex ante* MWTP to avoid a statistical day of LRS as defined by Schwartz is therefore the average of the MWTPs to avoid each type of LRS, or $11.82. This is the point estimate used in the benefit analysis for the dollar value for LRS as defined by Schwartz et al. The WTP estimates are based on studies which considered the value of a *day* of avoided symptoms, whereas the Schwartz study used as its measure a *case* of LRS. Because a case of LRS usually lasts at least 1day, and often more, WTP to avoid a day of LRS should be a conservative estimate of WTP to avoid a case of LRS.

Finally, as with URS, it is worth emphasizing that what is being valued here is LRS *as defined by Schwartz et al., 1994.* While other definitions of LRS are certainly possible, this definition of LRS is used in this benefit analysis because it is the incidence of this specific definition of LRS that has been related to PM exposure by Schwartz et al., 1994.

The point estimates derived for MWTP to avoid a day of URS and a case of LRS are based on the assumption that WTPs are additive. For example, if WTP to avoid a day of cough is $7.00, and WTP to avoid a day of shortness of breath is $5.00, then WTP to avoid a day of both cough and shortness of breath is $12.00. If there are no synergistic effects among symptoms, then it is likely that the marginal utility of avoiding symptoms decreases with the number of symptoms being avoided. If this is the case, adding WTPs would tend to overestimate WTP for avoidance of multiple symptoms. However, there may be synergistic effects -- that is, the discomfort from two or more simultaneous symptoms may exceed the sum of the discomforts associated with each of the individual symptoms. If this is the case, adding WTPs would tend to underestimate WTP for avoidance of multiple symptoms. It is also possible that people may experience additional symptoms for which WTPs are not available, again leading to an underestimate of the correct WTP. However, for small numbers of symptoms, the assumption of additivity of WTPs is unlikely to result in substantive bias.

9.5.6 Work loss days

9.5.6.1 *Measuring Reductions in Work Loss Days*

A study by Ostro (1987) provides the relationship between ambient PM concentrations and work loss days. Ostro (1987) estimated the impact of PM on the incidence of work-loss days (WLD) in a national sample of the adult working population, ages 18 to 65, living in metropolitan areas. Separate coefficients were developed for each year in the analysis (1976-1981); we then combined these coefficients for use in this analysis.

9.5.6.2 *Valuing Reductions in Work Loss Days*

Thgr WTP to avoid the loss of 1 day of work was estimated by dividing the median weekly wage for 1990 (U.S. Department of Commerce, 1992) by 5 (to get the median daily wage). This values the loss of a day of work at the median wage for the day lost. Valuing the loss of a day's work at the wages lost is consistent with economic theory, which assumes that an individual is paid exactly the value of his labor.

The use of the median rather than the mean, however, requires some comment. If all individuals in society were equally likely to be affected by air pollution to the extent that they lose a day of work because of it, then the appropriate measure of the value of a work loss day would be the mean daily wage. It is highly likely, however, that the loss of work days due to pollution exposure does not occur with equal probability among all individuals, but instead is more likely to occur among lower income individuals than among high income individuals. It is probable, for example, that individuals who are vulnerable enough to the negative effects of air pollution to lose a day of work as a result of exposure tend to be those with generally poorer health care. Individuals with poorer health care have, on average, lower incomes. To estimate the average lost wages of individuals who lose a day of work because of exposure to PM pollution, then, would require a weighted average of all daily wages, with higher weights on the low end of the wage scale and lower weights on the high end of the wage scale. Because the appropriate weights are not known, however, the median wage was used rather than the mean wage. The median is more likely to approximate the correct value than the mean because means are highly susceptible to the influence of large values in the tail of a distribution (in this case, the small percentage of very large incomes in the United States), whereas the median is not susceptible to these large values. The median daily wage in 1990 was $83.00.

9.5.7 Minor Restricted Activity Days (MRAD)

9.5.7.1 *Measuring Avoided MRAD*

Ostro and Rothschild (1989) estimated the impact of $PM_{2.5}$ on the incidence of minor restricted activity days (MRAD) in a national sample of the adult working population, ages 18 to 65, living in metropolitan areas. We developed separate coefficients for each year in the analysis (1976-1981), which were then combined for use in this analysis.

9.5.7.2 *Valuing Avoided MRAD*

No studies are reported to have estimated WTP to avoid a MRAD. However, IEc (1993) has derived an estimate of WTP to avoid a minor respiratory restricted activity day (MRRAD), using WTP estimates from Tolley et al. (1986) for avoiding a three symptom combination of coughing, throat congestion, and sinusitis. This estimate of WTP to avoid a MRRAD, so defined, is $38.37. Although Ostro and Rothschild (1989) estimated the relationship between PM-2.5 and MRADs, rather than MRRADs (a component of MRADs), it is likely that most of the MRADs associated with exposure to PM-2.5 are in fact MRRADs. For the purpose of valuing this health endpoint, then, it is assumed that MRADs associated with PM exposure may be more specifically defined as MRRADs, and the estimate of MWTP to avoid a MRRAD is used.

Any estimate of MWTP to avoid a MRRAD (or any other type of restricted activity day other than WLD) will be somewhat arbitrary because the endpoint itself is not precisely defined. Many different combinations of symptoms could presumably result in some minor or less minor restriction in activity. It has been argued (Krupnick and Kopp, 1988) that mild symptoms will not be sufficient to result in a MRRAD, so that WTP to avoid a MRRAD should exceed WTP to avoid any single mild symptom. A single severe symptom or a combination of symptoms could, however, be sufficient to restrict activity. Therefore, WTP to avoid a MRRAD should, these authors argue, not necessarily exceed WTP to avoid a single severe symptom or a combination of symptoms. The "severity" of a symptom, however, is similarly not precisely defined; moreover, one level of severity of a symptom could induce restriction of activity for one individual while not doing so for another. The same is true for any particular combination of symptoms.

Given that there is inherently a substantial degree of arbitrariness in any point estimate of WTP to avoid a MRRAD (or other kinds of restricted activity days), the reasonable bounds on such an estimate are considered. By definition, a MRRAD does not result in loss of work. The WTP to avoid a MRRAD should therefore be less than WTP to avoid a WLD. At the other extreme, WTP to avoid a MRRAD should exceed WTP to avoid a single mild symptom. The highest IEc midrange estimate of WTP to avoid a single symptom is $15.72, for eye irritation. The point estimate of WTP to avoid a WLD in the benefit analysis is $83. If all the single symptoms evaluated by the studies listed in Exhibit 4.5 are not severe, then the estimate of WTP to avoid a MRRAD should be somewhere between $15.72 and $83.00. Because the IEc estimate of $38.37 falls within this range (and acknowledging the degree of arbitrariness associated with any estimate within this range), the IEc estimate is used as the point estimate of MWTP to avoid a MRRAD.

9.5.8 Household Soiling Damage

Welfare benefits also accrue from avoided air pollution damage, both aesthetic and structural, to architectural materials and to culturally important articles. At this time, data limitations preclude the ability to quantify benefits for all materials whose deterioration may be promoted and accelerated by air pollution exposure. However, this analysis addresses one small effect in this category, the soiling of households by PM.

Assumptions regarding the air quality indicator are necessary to evaluate the concentration-response function. The PM_{10} and $PM_{2.5}$ are both components of total suspended particulates (TSP). However, it is not clear which components of TSP cause household soiling damage. The Criteria Document cites some evidence that smaller particles may be primarily responsible, in which case these estimates are conservative.

Several studies have provided estimates of the cost to households of PM soiling. The study that is cited by ESEERCO (1994) as one of the most sophisticated and is relied upon by EPA in its 1988 RIA for SO_2 is Manuel et al. (1982). Using a household production function approach and household expenditure data from the 1972-73 Bureau of Labor Statistics Consumer Expenditure Survey for over twenty cities in the United States, Manuel et al. estimate the annual cost of cleaning per $\mu g/m^3$ PM per household as \$1.26 (\$0.48 per person times 2.63 persons per household). This estimate is low compared with others (e.g., estimates provided by Cummings et al., 1981, and Watson and Jaksch, 1982, are about eight times and five times greater, respectively). The ESEERCO report notes, however, that the Manuel estimate is probably downward biased because it does not include the time cost of do-it-yourselfers. Estimating that these costs may comprise at least half the cost of PM-related cleaning costs, they double the Manuel et al. estimate to obtain a point estimate of \$2.52 (reported by ESEERCO in 1992 dollars as \$2.70).

9.5.9 Nitrogen Deposition

Excess nutrient loads, especially that of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure. Direct C-R functions relating deposited nitrogen and reductions in estuarine benefits are not available. The preferred WTP based measure of benefits depends on the availability of these C-R functions and on estimates of the value of environmental responses. Because neither appropriate C-R functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, this analysis used an avoided cost approach instead of WTP to generate estuary-related benefits.

The use of the avoided cost approach to establish the value of a reduction in nitrogen deposition is problematic, because there is not a direct link between implementation of the air pollution regulation and the abandonment of a separate costly regulatory program by some other agency, (i.e. a state environmental agency). However, there are currently no readily available alternatives to this approach.[7]

The avoided costs to surrounding communities of reduced nitrogen loadings were calculated for three case study estuaries.[8] These costs are used to estimate the avoided costs for ten East Coast estuaries, and two Gulf Coast case study estuaries for which reduced nitrogen loadings were modeled.[9] The avoided cost estimates for the ten East Coast case study estuaries, which represent approximately half of the estuarine watershed area in square miles along the East Coast, are then used to extrapolate avoided costs to all East Coast estuaries. The three case study estuaries are chosen because they have agreed upon nitrogen reduction goals and the necessary nitrogen control cost data. The remaining estuaries in this analysis are chosen based on their potential representativeness and our ability to estimate the direct and indirect nitrogen load from atmospheric deposition.

Our analysis values atmospheric nitrogen reductions on the basis of avoided costs associated with agreed upon controls of nonpoint water pollution sources. We estimated benefits using a weighted-average, locally-based cost for nitrogen removal from water pollution (U.S. EPA, 1998a). Valuation reflects water pollution control cost avoidance based on the weighted average cost/pound of current non-point source water pollution controls for nitrogen in the three case study estuaries. Taking the weighted cost/pound of these available controls assumes States will combine low cost and high cost controls, which could inflate avoided cost estimates.

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[7] Avoided cost is only a proxy for benefits, and should be viewed as inferior to willingness-to-pay based measures. Current research is underway to develop other approaches for valuing estuarine benefits, including contingent valuation and hedonic property studies. However, this research is still sparse, and does not contain sufficient information on the marginal willingness-to-pay for changes in concentrations of nitrogen (or changes in water quality or water resources as a result of changes in nitrogen concentrations).

[8] The case study estuaries are Albemarle-Pamlico Sounds, Chesapeake Bay, and Tampa Bay.

[9] The ten East Coast estuaries are Albemarle-Pamlico Sounds, Cape Cod Bay, Chesapeake Bay, Delaware Bay, Delaware Inland Bays, Gardiners Bay, Hudson River/Raritan Bay, Long Island Sound, Massachusetts Bays, and Narragansett Bays. The Gulf Coast estuaries are Sarasota Bay and Tampa Bay.

Reductions in nitrogen deposition from the RH rule should have relatively minor impacts on estuaries along the eastern seaboard and the Gulf Coast. Nitrogen reduction programs are currently targeting many of the estuaries in these areas due to current impairment of estuarine water quality by excess nutrients. Some of the largest of these estuaries, including the Chesapeake Bay, have established goals for nitrogen reduction and target dates by which these goals should be achieved. Using the best and most easily implemented existing technologies, many of the estuaries will not be able to achieve the stated goals by the target dates. Meeting these additional reductions will require development of new technologies, implementation of costly existing technologies (such as stormwater controls), or use of technologies with significant implementation difficulties, such as agricultural best management practices (BMPs). Reductions in nitrogen deposition from the atmosphere will directly reduce the need for these additional costly controls. Thus, while the RH rule does not eliminate the need for nutrient management programs already in place, it may substitute for some of the incremental costs and programs (such as an agricultural BMP program) necessary to meet the nutrient reduction goals for each estuary.

We calculated the total fixed capital cost per pound (weighted on the basis of fractional relationship of nitrogen load controlled for the estuary goal) for each of the case-study estuaries and applied in the valuation of their avoided nitrogen load controlled. The weighted capital costs per pound for the case-study estuaries are $33.35 for Albemarle-Pamlico Sounds, $21.82 for Chesapeake Bay, and $88.24 for Tampa Bay[10]. For the purposes of our analysis, EPA assumes that estuaries that have not yet established nutrient reduction goals will utilize the same types of nutrient management programs as projected for the case study estuaries. For the other nine estuaries, an average capital cost per pound of nitrogen (from the three case-estuaries) of $47.80/lb is calculated and applied; it is unclear whether this cost understates or overstates the costs associated with reductions in these other estuaries. The other nine estuaries generally represent smaller, more urban estuaries (like Tampa Bay), which typically have fewer technical and financial options available to control nitrogen loadings from nonpoint sources. This may result in higher control costs more similar to the Tampa Bay case. On the other hand, these estuaries may have opportunities to achieve additional point source controls at lower costs. Also, increased public awareness of nutrification issues and technological innovation may, in the future, result in States finding lower cost solutions to nitrogen removal.

The benefits analysis assumed that the ten included East Coast estuaries are highly or moderately nutrient sensitive, and they represent approximately 45.46 percent of all estuarine

[10] The value for Tampa Bay is not a true weighted cost per pound, but a midpoint of a range of $71.89 to $144.47 developed by Apogee Research for the control possibilities (mostly urban BMPs) in the Tampa Bay estuary.

watershed area along the East Coast.[11] Because the National Oceanic Atmospheric Administration (NOAA) data indicate that approximately 92.6 percent of the watershed and surface area of East Coast estuaries are highly or moderately nutrient sensitive, it is reasonable to expect that East Coast estuaries not included in this analysis would also benefit from reduced deposition of atmospheric nitrogen. Therefore, we scaled-up total benefits from the ten representative East Coast estuaries to include the remainder of the nutrient sensitive estuaries along the East Coast on the basis of estuary watershed plus water surface area. Since the ten estuaries are assumed to be nutrient sensitive and account for 48 percent of total eastern estuarine area, we scaled-up estimates by multiplying the estimate for the ten East Coast estuaries by 2.037 (equal to 92.6 percent divided by 45.46 percent). We then added this figure to the benefits estimated for the two Gulf Coast estuaries for a total benefits estimate for nitrogen deposition. Changes in nitrogen deposition to other Gulf Coast estuaries and estuaries in the western U.S. are not valued in this analysis, due to limitations in data on nutrient sensitivity in these estuaries and differences in estuarine conditions between eastern and western estuaries. Estimated nitrogen deposition benefits for eastern estuaries are thus expected to be an underestimate of national nitrogen deposition benefits.

We then than annualized all capital cost estimates based on a 7 percent discount rate and a typical implementation horizon for control strategies. Based on information from the three case study estuaries, this typically ranges from 5 to 10 years. The EPA has used the midpoint of 7.5 years for annualization, which yields an annualization factor of 0.1759. Non-capital installation costs and annual operating and maintenance costs are not included in these annual cost estimates. Depending upon the control strategy, these costs can be significant. Reports on the Albemarle-Pamlico Sounds indicate, for instance, that planning costs associated with control measures comprises approximately 15 percent of capital costs. Information received from the Association of National Estuary Programs indicates that operating and maintenance costs are about 30 percent of capital costs, and that permitting, monitoring, and inspections costs are about 1 to 2 percent of capital costs. For these reasons, the annual cost estimates may be understated.

9.6 Summary of Benefit Estimates

The dollar benefit from reducing light extinction and PM concentrations resulting from implementing the illustrative RH goals is the sum of dollar benefits from the reductions in incidence of all non-overlapping health and welfare endpoints associated with PM and light extinction for a given set of assumptions.

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[11] There are 43 East Coast estuaries of which ten were in the sample, and 31 Gulf of Mexico estuaries of which two are in the sample.

There is uncertainty about the magnitude of the total monetized benefits associated with any of the illustrative visibility goals examined in the benefits analysis. The benefits are uncertain because there is uncertainty surrounding each of the factors that affect these benefits: the changes in ambient pollutant concentrations that will result from implementation of controls to achieve the illustrative goal; the relationship between these changes in pollutant concentrations and each of the associated health and welfare endpoints; and the value of each adverse health and welfare effect avoided by the reduction in pollutant concentrations.

Some of this uncertainty derives from uncertainty about the true values of analysis components, such as the value of the PM coefficient in a concentration-response function relating PM to a particular health endpoint, or the true dollar value of an avoided hospital admission for congestive heart failure. The analysis relies on estimates of these parameters, but the true values being estimated are unknown. This type of uncertainty can often be quantified. For example, the uncertainty about pollutant coefficients is typically quantified by reported standard errors of the estimates of the coefficients in the concentration-response functions estimated by epidemiological studies. A formal quantitative analysis of the statistical uncertainty imparted to the benefits estimates by the variability in the underlying concentration-response and valuation functions can be found in the technical support document for this benefits analysis (Abt Associates, 1999).

Some of the uncertainty surrounding the results of the benefits analysis, however, involves basically discrete choices and is less easily quantified. For example, the decision of whether to include both residential and recreational visibility to obtain total visibility benefits is largely subjective. Decisions and assumptions must be made at many points in an analysis in the absence of complete information. The estimate of total benefits is sensitive to the decisions and assumptions made. Five of the most critical of these are the following:

- **$PM_{2.5}$ concentration threshold:** Health effects are measured only down to the assumed ambient concentration threshold. Changes in air quality below the threshold will have no impact on estimated benefits. The EPA's Science Advisory Board has recommended examining alternative thresholds. For this analysis, three threshold assumptions were examined: anthropogenic background, the lowest observed level in the health endpoint study, and 15 $\mu g/m^3$ (or the equivalent of 50 $\mu g/m^3$ for PM10 functions).

- **Value of Avoided Incidences of Premature Mortality:** There are two alternative assumptions concerning the appropriate value for an avoided incidence of PM-related premature mortality: 1) avoided incidences should be valued using a value of a statistical life equal to $4.8 million (1990$), or 2) avoided incidences should be valued based on the number of statistical life years saved. Based on the $4.8 million VSL, a 5% discount rate, and an average of 9.8 statistical life years saved, this yields a value for an avoided incidence of premature mortality of $2.2 million (1990$).

- **Value of Avoided Incidences of Chronic Bronchitis (CB):** There are two alternative assumptions concerning the appropriate value for an avoided incidence of PM-related CB: 1) avoided incidences should be valued using the measure of WTP derived from Viscusi, et al (1991) and Krupnick and Cropper (1992), equal to $260,000 per case, or 2) avoided incidences should be values based on a cost-of-illness approach, which yields a value of $59,000 per case.

- **Residential Visibility:** The McClelland et al. survey which forms the basis for the WTP estimate for changes in visibility outside of Class I areas (residential visibility) has several weaknesses which call into question the reliability of the estimated WTP values. There are two alternative assumptions about residential visibility: 1) estimates of benefits based on the WTP value from the McClelland et al. study accurately reflect true WTP for changes in residential visibility and should thus be included in an estimate of total visibility benefits, or 2) estimates of benefits based on the WTP value from the McClelland et al. study are biased to the point of seriously under or overstating the benefits of residential visibility changes and should not be included in an estimate of total visibility benefits.

- **Visibility Changes at Forest Service Class I Areas:** The Chestnut and Rowe survey which forms the basis for the WTP estimate for changes in recreational visibility only elicited WTP for changes in visibility at Class I areas managed by the NPS. Two alternative assumptions may be considered for valuing changes in visibility at Class I areas not managed by the NPS: (1) values for visibility resources at non-NPS Class I areas are embedded in the WTP value for visibility changes in a region stated by respondents and thus total WTP for visibility changes in a region will not change, although the apportionment of WTP to individual parks in a region will, or (2) values for visibility resources at non-NPS managed Class I areas are additive to the stated values for visibility changes in the NPS Class I areas and thus WTP for visibility changes for all Class I areas in a region will exceed that for just the visibility changes at NPS Class I areas.

A range of total benefits reflecting sensitivity to the above assumptions can be formed by selecting assumptions to yield a low-end and a high-end estimate. The low end of the benefits range is constructed by assuming 1) the PM health-effects threshold is equal to 15 $\mu g/m^3$, 2) the value of an avoided incidence of PM-related premature mortality is equal to $2.2 million, 3) the value of an avoided case of CB is equal to $63,500, 4) the value of residential visibility changes is not included in the estimate of total visibility benefits, and 5) WTP for visibility changes at non-NPS Class I areas are assumed to be included in the stated WTP for visibility changes in a region.

The high end of the benefits range is constructed by assuming 1) the PM health effects threshold is equal to anthropogenic background, 2) the value of an avoided incidence of PM-related premature mortality is equal to $4.8 million, 3) the value of avoided case of CB is equal to $260,000, 4) total visibility benefits is the sum of residential and recreational visibility benefits ,and 5) WTP for visibility changes at non-NPS Class I areas is additive to WTP for NPS Class I areas in a study region.

9.6.1 Total Benefits - Case A

Table 9-20 presents a summary of the monetary values for each broad benefit category (visibility, PM health, and PM welfare) and the estimate of total benefits for each of the four regulatory alternatives under emission control Case A. Aggregate results are presented for the low-end and high-end assumption sets defined above. Monetized benefits are estimated for the 2015 analytical year. Estimates of monetized benefits for 2015 are representative of annual benefits expected from all regions selecting an illustrative goal and are not an estimate of the discounted value of the stream of future benefits in 2015.

Table 9-10
Total Quantified Monetary Benefits in 2015 Associated with the Regional Haze Rule, Incremental to the 2010 Base Case: Case A, Fugitive Dust Controls Considered[a]

Illustrative Goal	Benefit Category	Low-end		High-end	
		Millions 1990$	% of Total	Millions 1990$	% of Total
1.0 dv/15 years	Visibility	$1,043	77.5%	$1,191	21.4%
	PM-Health	$260	19.3%	$4,325	77.8%
	PM-Welfare	$42	3.1%	$42	0.8%
	Total	**$1,345**		**$5,558**	
1.0 dv/10 years	Visibility	$1,426	78.6%	$1,632	23.0%
	PM-Health	$333	18.3%	$5,418	76.2%
	PM-Welfare	$56	3.1%	$56	0.8%
	Total	**$1,815**		**$7,106**	
5% dv/10 years	Visibility	$1,258	78.1%	$1,447	21.3%
	PM-Health	$304	18.9%	$5,307	78.0%
	PM-Welfare	$49	3.0%	$49	0.7%
	Total	**$1,611**		**$6,803**	
10% dv/10 years	Visibility	$1,726	67.3%	$2,269	12.1%
	PM-Health	$729	28.4%	$16,361	87.3%
	PM-Welfare	$109	4.3%	$109	0.6%
	Total	**$2,564**		**$18,739**	

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 9-2.

Several important results from Table 9-10 should be highlighted. First, note that visibility and PM-related health benefits account for over 95 percent of total benefits in all cases. Second, note that as the PM health threshold is lowered, visibility accounts for a lower percentage of benefits, while PM health benefits account for up to 87 percent of total benefits. This suggests that the threshold assumption is important both in determining total benefits, but also in determining the importance of visibility relative to ancillary benefits in determining overall benefits. Finally, it is important to note that three of the four illustrative goals (1.0 dv/10 years, 1.0 dv/15 years, 5% dv/10 years) lead to total benefits differing by a maximum of 34 percent, while the benefits associated with the 10% dv/10 years goal are between 71 and 164 percent greater than the most stringent of the remaining three goals, depending on the assumed threshold. This is due in large part to the magnitude of mortality-related benefits associated with this goal, although visibility benefits are 39 percent larger under the 10% dv/10 year goal relative to the 1.0 dv/10 year goal.

9.6.2 Total Benefits - Case B

Table 9-11 presents a summary of the monetary values for each broad benefit category (visibility, PM health, and PM welfare) and the estimate of total benefits for each of the four regulatory alternatives under emission control Case B. Aggregate results are presented for the low-end and high-end assumption sets defined above. Monetized benefits are estimated for the 2015 analytical year. Estimates of monetized benefits for 2015 are representative of annual benefits expected from all regions selecting an illustrative goal and are not an estimate of the discounted value of the stream of future benefits in 2015.

Table 9-11

Total Quantified Monetary Benefits in 2015 Associated with the Regional Haze Rule, Incremental to the 2010 Base Case: Case B, Fugitive Dust Controls Not Considered[a]

Illustrative Goal	Benefit Category	Low-end		High-end	
		Millions 1990$	% of Total	Millions 1990$	% of Total
1.0 dv/15 years	Visibility	$642	79.6%	$762	17.8%
	PM-Health	$146	18.1%	$3,494	81.7%
	PM-Welfare	$19	2.3%	$19	0.5%
	Total	**$807**		**$4,275**	
1.0 dv/10 years	Visibility	$829	71.1%	$1,025	10.5%
	PM-Health	$296	25.4%	$8,661	89.1%
	PM-Welfare	$41	3.5%	$41	0.4%
	Total	**$1,166**		**$9,727**	
5% dv/10 years	Visibility	$788	68.9%	$977	10.4%
	PM-Health	$315	27.6%	$8,389	89.2%
	PM-Welfare	$40	3.5%	$40	0.4%
	Total	**$1,143**		**$9,406**	
10% dv/10 years	Visibility	$1,156	62.8%	$1,549	8.0%
	PM-Health	$606	32.9%	$17,726	91.6%
	PM-Welfare	$78	4.3%	$78	0.4%
	Total	**$1,840**		**$19,353**	

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 9-2.

Several important results from Table 9-11 should be highlighted. First, note that visibility and PM-related health benefits account for over 95 percent of total benefits in all cases. Second, note that as the PM health threshold is lowered, visibility accounts for a lower percentage of benefits, while PM health benefits account for up to 92 percent of total benefits. This suggests that the threshold assumption is important both in determining total benefits, but also in determining the importance of visibility relative to ancillary benefits in determining overall benefits.

9.7 Detailed Estimates of Avoided Incidences and Monetary Benefits -- Case A

Estimates of the monetized value of the changes in incidences of health and welfare endpoints are obtained by application of the concentration-response functions and unit dollar values described above to the changes in air quality described in chapter 4. Results in this section are for the air quality changes associated with emissions reductions obtained from applying the controls available in Case A (fugitive dust controls included). Results are presented for the four illustrative goals outlined in Chapter 3. For simplicity of presentation, the detailed results presented in the tables below are based on using the VSL approach to value premature mortality and the contingent valuation estimates of WTP for avoided incidences of chronic bronchitis. Estimates using the VSLY approach for premature mortality and the cost-of-illness approach for chronic bronchitis will lead to significantly lower estimates of the benefits estimates for these endpoints for all threshold levels. Estimates based on these alternative approaches are used to form the range of aggregate monetized benefits presented in Table 9-10. Because of its large impacts on PM-health benefits, results for PM-related health endpoints are presented for the three alternative PM health effect threshold levels, anthropogenic background, lowest observed level or background (LOL), and 15 $\mu g/m^3$. Monetized benefits are estimated for the 2015 analytical year. Estimates of monetized benefits for 2015 are representative of annual benefits expected from all regions selecting an illustrative goal and are not an estimate of the discounted value of the stream of future benefits in 2015.

Annual baseline incidence rates and baseline incidences for the affected populations for PM-related health endpoints are useful to put avoided incidences resulting from the RH rule in context. Incidence rates are not available for all health endpoints, however, information is available for mortality, hospital admissions, URS, work loss days, and MRAD. Table 9-12 lists the baseline incidence rates and affected populations for the above listed endpoints.

Table 9-12
Baseline Incidence Rates and Incidences for Selected PM-related Health Endpoints

PM Health Endpoint	Affected Population	Baseline Incidence Rate	Baseline Incidence
Mortality from long-term exposure	over 30 years old	759 per 100,000 (non-accidental deaths)	1,330,967 (non-accidental deaths)
Hospital Admissions - All respiratory	general population	504 per 100,000	1,500,488
Hospital Admissions - Congestive Heart Failure	general population	231 per 100,000	687,724
Hospital Admissions - Ischemic Heart Disease	general population	450 per 100,000	1,339,722
Upper Respiratory Symptoms	asthmatics, ages 9 to 11	—	38,187
Work Loss Days	workers, ages 18 to 65	150,750 days per year per 100,000 workers	—
Minor Restricted Activity Days	ages 18 to 65	150,750 days per year per 100,000 population	1,450,000,000

9.7.1 Results

Tables 9-13 through 9-16 present estimates of the avoided incidences of PM-related health effects and monetary benefits associated with visibility changes and avoided PM-related health and welfare effects for the four illustrative visibility goals for emission control Case A.

Table 9-13
Estimated Benefits in 2015 Associated with the Regional Haze Rule: 1.0 dv/15 years Visibility Goal, Case A

Endpoint	Avoided Incidences (cases/year)			Monetary Benefits (millions 1990$)		
	15 μg/m^3	LOL	Back ground	15 μg/m^3	LOL	Back ground
Visibility Endpoints						
Residential	direct economic valuation			$83	$83	$83
National Park Recreational	direct economic valuation			$983	$983	$983
Wilderness Area Recreational	direct economic valuation			$60	$60	$60
Total Visibility[a]				**$1,126**	**$1,126**	**$1,126**
PM-related Health Endpoints						
Mortality	15	280	696	$70	$1,330	$3,300
Chronic Bronchitis	3,333	3,369	3,369	$954	$964	$964
Hospital Admissions - AR[b]	125	265	265	$0.8	$1.7	$1.7
Hospital Admissions - CHF[b]	92	102	102	$0.8	$0.8	$0.8
Hospital Admissions - IHD[b]	102	113	113	$1.0	$1.2	$1.2
Acute Bronchitis	56	443	1,511	$0.0	$0.0	$0.1
LRS	7,281	15,367	15,367	$0.1	$0.2	$0.2
URS	2,917	3,241	3,241	$0.1	$0.1	$0.1
Work Loss Days	67,064	142,145	142,145	$6	$12	$12
MRAD	559,041	1,185,688	1,185,688	$21	$45	$45
Total PM-related Health	—	—	—	**$1,054**	**$2,355**	**$4,325**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$42	$42	$42
Nitrogen Deposition	direct economic valuation			$0.0	$0.0	$0.0
Total PM-related Welfare				**$42**	**$42**	**$42**
Total	—	—	—	**$2,222**	**$3,523**	**$5,493**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

Table 9-14
Estimated Benefits in 2015 Associated with the Regional Haze Rule: 1.0 dv/10 years Visibility Goal, Case A

Endpoint	Avoided Incidences (cases/year)			Monetary Benefits (millions 1990$)		
	15 μg/m^3	LOL	Back ground	15 μg/m^3	LOL	Back ground
Visibility Endpoints						
Residential	direct economic valuation			$117	$117	$117
National Park Recreational	direct economic valuation			$1,337	$1,337	$1,337
Wilderness Area Recreational	direct economic valuation			$88	$88	$88
Total Visibility[a]				**$1,542**	**$1,542**	**$1,542**
PM-related Health Endpoints						
Mortality	15	247	855	$72	$1,171	$4,056
Chronic Bronchitis	4,462	4,507	4,507	$1,277	$1,289	$1,289
Hospital Admissions - AR[b]	150	318	318	$1.0	$2.0	$2.0
Hospital Admissions - CHF[b]	117	132	132	$1.0	$1.1	$1.1
Hospital Admissions - IHD[b]	130	147	147	$1.3	$1.5	$1.5
Acute Bronchitis	64	535	2,021	$0.0	$0.0	$0.1
LRS	8,655	18,244	18,244	$0.1	$0.2	$0.2
URS	3,639	4,080	4,080	$0.1	$0.1	$0.1
Work Loss Days	80,106	169,788	169,788	$7	$14	$14
MRAD	667,701	1,416,360	1,416,360	$26	$54	$54
Total PM-related Health	—	—	—	**$1,386**	**$2,533**	**$5,418**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$56	$56	$56
Nitrogen Deposition	direct economic valuation			$0.1	$0.1	$0.1
Total PM-related Welfare				**$56**	**$56**	**$56**
Total	—	—	—	**$2,984**	**$4,131**	**$7,016**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

Table 9-15
Estimated Benefits in 2015 Associated with the Regional Haze Rule: 5% dv/10 years Visibility Goal, Case A

Endpoint	Avoided Incidences (cases/year)			Monetary Benefits (millions 1990$)		
	15 μg/m³	LOL	Back ground	15 μg/m³	LOL	Back ground
Visibility Endpoints						
Residential	direct economic valuation			$112	$112	$112
National Park Recreational	direct economic valuation			$1,180	$1,180	$1,180
Wilderness Area Recreational	direct economic valuation			$78	$78	$78
Total Visibility[a]				**$1,370**	**$1,370**	**$1,370**
PM-related Health Endpoints						
Mortality	17	316	865	$82	$1,499	$4,103
Chronic Bronchitis	3,905	3,944	3,944	$1,117	$1,128	$1,128
Hospital Admissions - AR[b]	154	327	327	$1.0	$2.1	$2.1
Hospital Admissions - CHF[b]	101	114	114	$0.8	$0.9	$0.9
Hospital Admissions - IHD[b]	113	126	126	$1.2	$1.3	$1.3
Acute Bronchitis	66	515	1,898	$0.0	$0.0	$0.1
LRS	8,869	18,847	18,847	$0.1	$0.2	$0.2
URS	3,222	3,600	3,600	$0.1	$0.1	$0.1
Work Loss Days	82,245	175,459	175,459	$7	$15	$15
MRAD	685,328	1,463,243	1,463,243	$26	$56	$56
Total PM-related Health	—	—	—	**$1,235**	**$2,703**	**$5,307**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$49	$49	$49
Nitrogen Deposition	direct economic valuation			$0.0	$0.0	$0.0
Total PM-related Welfare				**$49**	**$49**	**$49**
Total	—	—	—	**$2,654**	**$4,122**	**$6,726**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

Table 9-16

Estimated Benefits in 2015 Associated with the Regional Haze Rule: 10% dv/10 years Visibility Goal, Case A

Endpoint	**Avoided Incidences (cases/year)**			**Monetary Benefits (millions 1990$)**		
	15 µg/m³	**LOL**	**Back ground**	**15 µg/m³**	**LOL**	**Back ground**
Visibility Endpoints						
Residential	direct economic valuation			$306	$306	$306
National Park Recreational	direct economic valuation			$1,731	$1,731	$1,731
Wilderness Area Recreational	direct economic valuation			$124	$124	$124
Total Visibility[a]				**$2,161**	**$2,161**	**$2,161**
PM-related Health Endpoints						
Mortality	60	1,236	2,877	$284	$5,863	$13,643
Chronic Bronchitis	8,665	8,774	8,774	$2,479	$2,510	$2,510
Hospital Admissions - AR[b]	355	904	904	$2.3	$5.7	$5.7
Hospital Admissions - CHF[b]	237	272	272	$2.0	$2.3	$2.3
Hospital Admissions - IHD[b]	264	303	303	$2.7	$3.1	$3.1
Acute Bronchitis	102	1,245	5,304	$0.0	$0.1	$0.2
LRS	19,568	49,653	49,653	$0.2	$0.6	$0.6
URS	6,718	7,656	7,656	$0.1	$0.2	$0.2
Work Loss Days	191,242	486,681	486,681	$16	$40	$40
MRAD	1,593,098	4,058,430	4,058,430	$61	$156	$156
Total PM-related Health	—	—	—	**$2,847**	**$8,581**	**$16,361**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$108	$108	$108
Nitrogen Deposition	direct economic valuation			$0.9	$0.9	$0.9
Total PM-related Welfare				**$109**	**$109**	**$109**
Total	—	—	—	**$5,117**	**$10,851**	**$18,631**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

9.7.2 Discussion of Results

The results show that the imposition of a health effect threshold has a large impact on the PM2.5 based health functions. For the PM2.5 functions, up to 98 percent of total avoided incidences occur below the 15 µg/m^3 threshold. Health functions based on mean PM2.5 appear to be slightly more sensitive to the threshold level than functions based on the median.

Results also highlight the fact that the magnitude of incidences and the magnitude of monetary benefits for individual endpoints may not be strongly correlated. This is due to relatively large per-unit benefits associated with relatively low risk health endpoints, such as mortality and CB, and the relatively small per unit benefits associated with relatively high risk health endpoints, such as work loss days or MRADs. This highlights the importance of presenting both avoided incidences and monetary benefits to provide a complete picture of the impacts of a given air quality change.

The PM-related health benefits are dominated in all cases by two endpoints: mortality and CB. These two endpoints account for between 97 and 99 percent of all health benefits, depending on the threshold level assumed. The PM-related health benefits also dominate the other two benefit categories, visibility and PM-related welfare effects. Visibility accounts for between 12 and 52 percent of total benefits, depending on the visibility goal and the threshold level assumed.

9.8 Detailed Estimates of Avoided Incidences and Monetary Benefits -- Case B

Estimates of the monetized value of the changes in incidences of health and welfare endpoints are obtained by application of the concentration-response functions and unit dollar values described above to the changes in air quality described in chapter 4. Results in this section are for the air quality changes associated with emissions reductions obtained from applying the controls available in Case B (fugitive dust controls excluded). Results are presented for the four illustrative goals outlined in Chapter 3. For simplicity of presentation, the detailed results presented in the tables below are based on using the VSL approach to value premature mortality and the contingent valuation estimates of WTP for avoided incidences of chronic bronchitis. Estimates using the VSLY approach for premature mortality and the cost-of-illness approach for chronic bronchitis will lead to significantly lower estimates of the benefits estimates for these endpoints for all threshold levels. Estimates based on these alternative approaches are used to form the range of aggregate monetized benefits presented in Table 9-11. Because of its large impacts on PM-health benefits, results for PM-related health endpoints are presented for the three alternative PM health effect threshold levels, anthropogenic background, lowest observed level or background (LOL), and 15 µg/m^3. Monetized benefits are estimated for the 2015 analytical year.

Estimates of monetized benefits for 2015 are represenative of annual benefits expected from all regions selecting an illustrative goal and are not an estimate of the discounted value of the stream of future benefits in 2015.

Annual baseline incidence rates and baseline incidences for the affected populations for PM-related health endpoints are useful to put avoided incidences resulting from the RH rule in context. Incidence rates are not available for all health endpoints, however, information is available for mortality, hospital admissions, URS, WLDs, and MRAD. Table 9-17 lists the baseline incidence rates and affected populations for the above listed endpoints.

Table 9-17
Baseline Incidence Rates and Incidences for Selected PM-related Health Endpoints

PM Health Endpoint	Affected Population	Baseline Incidence Rate	Baseline Incidence
Mortality from long-term exposure	over 30 years old	759 per 100,000 (non-accidental deaths)	1,330,967 (non-accidental deaths)
Hospital Admissions - All respiratory	general population	504 per 100,000	1,500,488
Hospital Admissions - Congestive Heart Failure	general population	231 per 100,000	687,724
Hospital Admissions - Ischemic Heart Disease	general population	450 per 100,000	1,339,722
Upper Respiratory Symptoms	asthmatics, ages 9 to 11	—	38,187
Work Loss Days	workers, ages 18 to 65	150,750 days per year per 100,000 workers	—
Minor Restricted Activity Days	ages 18 to 65	150,750 days per year per 100,000 population	1,450,000,000

9.8.1 Results

Tables 9-18 through 9-21 present estimates of the avoided incidences of PM-related health effects and monetary benefits associated with visibility changes and avoided PM-related health and welfare effects for the four illustrative visibility goals.

Table 9-18

Estimated Benefits in 2015 Associated with the Regional Haze Rule:

1.0 dv/15 years Visibility Goal, Case B

Endpoint	Avoided Incidences (cases/year)			Monetary Benefits (millions 1990$)		
	15 μg/m³	LOL	Background	15 μg/m³	LOL	Background
Visibility Endpoints						
Residential	direct economic valuation			$82	$82	$82
National Park Recreational	direct economic valuation			$595	$595	$595
Wilderness Area Recreational	direct economic valuation			$47	$47	$47
Total Visibility[a]				**$724**	**$724**	**$724**
PM-related Health Endpoints						
Mortality	12	177	633	$58	$845	$3,014
Chronic Bronchitis	1,555	1,569	1,569	$419	$423	$423
Hospital Admissions - AR[b]	121	253	253	$0.8	$1.6	$1.6
Hospital Admissions - CHF[b]	40	45	45	$0.3	$0.4	$0.4
Hospital Admissions - IHD[b]	44	49	49	$0.5	$0.5	$0.5
Acute Bronchitis	56	445	1,651	$0.0	$0.0	$0.1
LRS	7,081	14,742	14,742	$0.1	$0.2	$0.2
URS	1,306	1,456	1,456	$0.0	$0.0	$0.0
Work Loss Days	63,826	133,452	133,452	$5	$11	$11
MRAD	531,817	1,112,777	1,112,777	$20	$43	$43
Total PM-related Health	—	—	—	**$504**	**$1,325**	**$3,494**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$19	$19	$19
Nitrogen Deposition	direct economic valuation			$0.0	$0.0	$0.0
Total PM-related Welfare				**$19**	**$19**	**$19**
Total	—	—	—	**$1,247**	**$2,068**	**$4,237**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

Table 9-19
Estimated Benefits in 2015 Associated with the Regional Haze Rule: 1.0 dv/10 years Visibility Goal, Case B

Endpoint	**Avoided Incidences (cases/year)**			**Monetary Benefits (millions 1990$)**		
	15 μg/m³	**LOL**	**Back ground**	**15 μg/m³**	**LOL**	**Back ground**
Visibility Endpoints						
Residential	direct economic valuation			$149	$149	$149
National Park Recreational	direct economic valuation			$766	$766	$766
Wilderness Area Recreational	direct economic valuation			$62	$62	$62
Total Visibility[a]				**$977**	**$977**	**$977**
PM-related Health Endpoints						
Mortality	34	589	1,602	$163	$2,802	$7,630
Chronic Bronchitis	3,348	3,374	3,374	$902	$909	$909
Hospital Admissions - AR[b]	226	539	539	$1.4	$3.4	$3.4
Hospital Admissions - CHF[b]	93	105	105	$0.8	$0.9	$0.9
Hospital Admissions - IHD[b]	103	117	117	$1.1	$1.2	$1.2
Acute Bronchitis	73	718	3,331	$0.0	$0.0	$0.1
LRS	12,554	29,719	29,719	$0.1	$0.4	$0.4
URS	2,611	2,941	2,941	$0.1	$0.1	$0.1
Work Loss Days	119,687	285,738	285,738	$10	$24	$24
MRAD	996,433	2,381,446	2,381,446	$38	$92	$92
Total PM-related Health	—	—	—	**$1,117**	**$3,833**	**$8,661**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$41	$41	$41
Nitrogen Deposition	direct economic valuation			$0.4	$0.4	$0.4
Total PM-related Welfare				**$41**	**$41**	**$41**
Total	—	—	—	**$2,135**	**$4,851**	**$9,679**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

Table 9-20

Estimated Benefits in 2015 Associated with the Regional Haze Rule:

5% dv/10 years Visibility Goal, Case B

Endpoint	Avoided Incidences (cases/year)			Monetary Benefits (millions 1990$)		
	15 µg/m³	LOL	Back ground	15 µg/m³	LOL	Back ground
Visibility Endpoints						
Residential	direct economic valuation			$144	$144	$144
National Park Recreational	direct economic valuation			$729	$729	$729
Wilderness Area Recreational	direct economic valuation			$59	$59	$59
Total Visibility[a]				**$932**	**$932**	**$932**
PM-related Health Endpoints						
Mortality	33	573	1,552	$158	$2,727	$7,390
Chronic Bronchitis	3,247	3,271	3,271	$875	$881	$881
Hospital Admissions - AR[b]	220	522	522	$1.4	$3.3	$3.3
Hospital Admissions - CHF[b]	90	102	102	$0.7	$0.8	$0.8
Hospital Admissions - IHD[b]	100	113	113	$1.0	$1.2	$1.2
Acute Bronchitis	74	701	3,224	$0.0	$0.0	$0.1
LRS	12,201	28,769	28,769	$0.1	$0.3	$0.3
URS	2,533	2,850	2,850	$0.0	$0.1	$0.1
Work Loss Days	116,493	277,142	277,142	$10	$23	$23
MRAD	969,869	2,309,839	2,309,839	$37	$89	$89
Total PM-related Health	—	—	—	**$1,083**	**$3,726**	**$8,389**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$40	$40	$40
Nitrogen Deposition	direct economic valuation			$0.4	$0.4	$0.4
Total PM-related Welfare				**$40**	**$40**	**$40**
Total	—	—	—	**$2,055**	**$4,698**	**$9,361**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

Table 9-21

Estimated Benefits in 2015 Associated with the Regional Haze Rule:

10% dv/10 years Visibility Goal, Case B

Endpoint	**Avoided Incidences (cases/year)**			**Monetary Benefits (millions 1990$)**		
	15 μg/m³	**LOL**	**Back ground**	**15 μg/m³**	**LOL**	**Back ground**
Visibility Endpoints						
Residential	direct economic valuation			$335	$335	$335
National Park Recreational	direct economic valuation			$1,071	$1,071	$1,071
Wilderness Area Recreational	direct economic valuation			$84	$84	$84
Total Visibility[a]				**$1,490**	**$1,490**	**$1,490**
PM-related Health Endpoints						
Mortality	67	1,467	3,317	$321	$6,983	$15,793
Chronic Bronchitis	6,238	6,310	6,310	$1,681	$1,700	$1,700
Hospital Admissions - AR[b]	386	1,028	1,028	$2.5	$6.5	$6.5
Hospital Admissions - CHF[b]	172	197	197	$1.4	$1.6	$1.6
Hospital Admissions - IHD[b]	190	218	218	$2.0	$2.2	$2.2
Acute Bronchitis	101	1,411	6,287	$0.0	$0.1	$0.3
LRS	21,176	56,216	56,216	$0.3	$0.7	$0.7
URS	4,778	5,439	5,439	$0.1	$0.1	$0.1
Work Loss Days	206,631	549,712	549,712	$17	$46	$46
MRAD	1,720,819	4,582,424	4,582,424	$66	$176	$176
Total PM-related Health	—	—	—	**$2,091**	**$8,916**	**$17,726**
PM-related Welfare Endpoints						
Household Soiling	direct economic valuation			$77	$77	$77
Nitrogen Deposition	direct economic valuation			$1.4	$1.4	$1.4
Total PM-related Welfare				**$78**	**$78**	**$78**
Total	—	—	—	**$3,659**	**$10,484**	**$19,294**

[a] Total visibility benefits are presented for the low-end assumption about wilderness areas, i.e., values for wilderness areas are assumed to have been included in the total regional value in the Chestnut and Rowe study. Residential visibility benefits are included in the total visibility benefits estimate.

[b] AR=all respiratory, CHF=congestive heart failure, IHD=ischemic heart disease.

9.8.2 Discussion of Results

The results show that the imposition of a health effect threshold has a large impact on PM2.5-based health functions. For the PM2.5 functions, up to 98 percent of total avoided incidences occur below the 15 $\mu g/m^3$ threshold. Health functions based on mean PM2.5 appear to be slightly more sensitive to the threshold level than functions based on the median.

Results also highlight the fact that the magnitude of incidences and the magnitude of monetary benefits for individual endpoints may not be strongly correlated. This is due to relatively large per unit benefits associated with relatively low risk health endpoints, such as mortality and CB, and the relatively small per unit benefits associated with relatively high risk health endpoints, such as WLDs or MRADs. This highlights the importance of presenting both avoided incidences and monetary benefits to provide a complete picture of the impacts of a given air quality change.

The PM-related health benefits are dominated in all cases by two endpoints: mortality and CB. These two endpoints account for between 95 and 99 percent of all health benefits, depending on the threshold level assumed. For most cases, PM-related health benefits also dominate the other two benefit categories, visibility and PM-related welfare effects. Visibility accounts for between 8 and 58 percent of total benefits, depending on the visibility goal and the threshold level assumed.

9.9 Regional Results

In addition to the national benefits analysis, benefits for emission control Case A were calculated for each of the six control cost regions defined in Chapter 6. This regional analysis was not conducted for emission control Case B. Tables 9-22 and 9-23 present summaries of the total benefits for each of the six control cost regions for the four illustrative visibility goals under the low-end and high-end sets of assumptions. Note that the benefits of visibility improvements are assigned to the region in which the visibility change takes place, rather than to the region in which the population valuing the change reside. Further analysis of the regional results for Case A is presented in Chapter 10., Benefit-Cost Comparisons.

Table 9-22

Summary Results from Regional Benefits Analyses, Low-end Estimates -- Case A[a]

Region	Total Monetized Benefits (million 1990$)			
	1.0 dv/15 years	1.0 dv/10 years	5% dv/10 years	10% dv/10 years
Northwest	$171	$223	$235	$446
West	$345	$465	$453	$560
Rocky Mountain	$680	$935	$754	$1,065
South Central	$68	$76	$72	$130
Midwest/Northeast	$36	$36	$40	$187
Southeast	$19	$45	$28	$239

[a] Total benefit estimates assume 1) residential visibility benefits excluded 2) WTP for visibility at non-NPS Class I areas is included in WTP for NPS Class I areas, 3) mortality is valued using the VSLY based VSL of $2.2 million, 4) chronic bronchitis is valued using cost of illness value of $59,000 per case, 5) Health effects threshold of 15 μg/m^3. Due to rounding, the sum of the regional benefits may not exactly equal the national estimates presented in Tables 9-11 through 9-14.

Table 9-23

Summary Results from Regional Benefits Analyses, High-end Estimates -- Case A[a]

Region	Total Monetized Benefits (million 1990$)			
	1.0 dv/15 years	1.0 dv/10 years	5% dv/10 years	10% dv/10 years
Northwest	$1,455	$1,848	$1,927	$3,285
West	$1,023	$1,275	$1,293	$1,706
Rocky Mountain	$1,183	$1,646	$1,370	$1,993
South Central	$642	$760	$720	$2,135
Midwest/Northeast	$970	$642	$1,059	$4,495
Southeast	$219	$840	$360	$5,030

[a] Total benefit estimates assume 1) both residential and recreational visibility benefits included 2) WTP for visibility at non-NPS Class I areas is addititive to WTP for NPS Class I areas, 3) mortality is valued using the $4.8 million VSL, 4) chronic bronchitis is valued using WTP of $260,000 per case, 5) Health effects threshold equal to anthropogenic background. Due to rounding, the sum of the regional benefits may not exactly equal the national estimates presented in Tables 9-11 through 9-14.

9.10 Plausibility Checks

Given the complexity of the benefits analysis and the damage-function approach to benefits estimation, it is important to check the plausibility of total benefits attributed to implementation of the illustrative visibility goals. One useful plausibility check is to present benefits on a per capita or per household basis for comparison with household income.

The RH rule is expected to impact the entire U.S. population, which is projected to 130 million households in 2010. The 2010 population projections are proxies for the population in the 2015 analysis year. Benefits per household for Case A, based on the projected population, are presented in Table 9-25. Benefits per household for Case B are presented in Table 9-26. Benefits per household are presented both for total benefits and for the health and visibility sub-categories. The per household values appear plausible, as even at the high-end estimate of benefits, benefits per household are small relative to total income.

Table 9-25

Monetized Benefits per Household in 2015 Associated with the Regional Haze Rule: Case A, Fugitive Dust Controls Considered[a]

Illustrative Goal	Benefit Category	1990 $ per Household	
		Low-end	**High-end**
1.0 dv/15 years	Visibility	$8	$9
	PM-Health	$2	$33
	Total	**$10**	**$43**
1.0 dv/10 years	Visibility	$11	$13
	PM-Health	$3	$42
	Total	**$14**	**$55**
5% dv/10 years	Visibility	$10	$11
	PM-Health	$2	$41
	Total	**$12**	**$52**
10% dv/10 years	Visibility	$13	$17
	PM-Health	$6	$126
	Total	**$20**	**$144**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 9-2.

Table 9-26

Monetized Benefits per Household in 2015 Associated with the Regional Haze Rule: Case B, Fugitive Dust Controls Not Considered[a]

Illustrative Goal	Benefit Category	1990 $ per Household	
		Low-end	High-end
1.0 dv/15 years	Visibility	$5	$6
	PM-Health	$1	$27
	Total	**$6**	**$33**
1.0 dv/10 years	Visibility	$6	$8
	PM-Health	$2	$67
	Total	**$9**	**$75**
5% dv/10 years	Visibility	$6	$8
	PM-Health	$2	$65
	Total	**$9**	**$73**
10% dv/10 years	Visibility	$9	$12
	PM-Health	$5	$136
	Total	**$14**	**$149**

[a] Not all possible benefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 9-2.

9.11 Limitations and Caveats to the Analysis

Given incomplete information, this national benefits analysis yields approximate results because of the uncertainty associated with any estimate. Potentially important sources of uncertainty exist and many of these are summarized in Table 9-27. These uncertainties can cause the total benefits estimate to be understated or overstated. Where possible, we state the direction of the bias presented by the uncertainty. Howeve,r in most cases, the effect of the uncertainly on total benefits is unknown (i.e., it could increase or decrease benefits depending on specific conditions. In most cases, there is no apparent bias associated with the uncertainty. For those cases for which the nature of the uncertainty suggests a direction of possible bias, this direction is noted in the table.

Table 9-27

Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions
-The value of the ozone- or PM-coefficient in each C-R function. -Application of a single C-R function to pollutant changes and populations in all locations. -Similarity of future year C-R relationships to current C-R relationships. -Correct functional form of each C-R relationship. (e.g., It is uncertain whether there are thresholds and, if so, what they are.) -Extrapolation of C-R relationships beyond the range of ozone or PM concentrations observed in the study.
2. Uncertainties Associated With Ozone and PM Concentrations
-Estimating future-year baseline and hourly ozone and daily PM concentrations. -Estimating the change in ozone and PM resulting from the control policy.
3. Uncertainties Associated with PM Mortality Risk
-No scientific basis supporting a plausible biological mechanism. -Potential causal agents within the complex mixture of PM responsible for the reported adverse health effects have not been identified. -While there were a great number of studies associated with PM_{10}, there were a limited number of studies that directly measured $PM_{2.5}$. -The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. -Estimated health effects levels associated with $PM_{2.5}$ exposure were small. -Possible confounding in the epidemiological studies of $PM_{2.5}$, effects with other factors (e.g., other air pollutants, weather, indoor/outdoor air, etc.). -The extent to which effects reported in the long-term studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. -Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects
-What portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year, and what portion might occur in subsequent years. Ignoring lags may lead to an overestimate of benefits.
5. Uncertainties Associated With Baseline Incidence Rates
-Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates. -Current baseline incidence rates may not well approximate what baseline incidence rates will be in the year 2007. -Projected population and demographics -- used to derive incidences – may not well approximate future-year population and demographics.
6. Uncertainties Associated With Economic Valuation
-Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. -Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors.
7. Uncertainties Associated With Aggregation of Monetized Benefits
-Health and welfare benefits estimates are limited to the available C-R functions, there may be components of total benefit omitted. Thus, unquantifiable benefit categories will cause total benefits to be underestimated.

9.11.1 Why Benefits Estimates May Be Understated

9.11.1.1 *Projected Income Growth*

This analysis does not attempt to adjust benefits estimates to reflect expected growth in real income. Economic theory argues, however, that WTP for most goods (such as environmental protection) will increase if real incomes increase. The degree to which WTP may increase for the specific visibility, health and welfare benefits associated with the illustrative RH visibility goals cannot be estimated due to insufficient income elasticity information.

9.11.1.2 Unquantified Benefit Categories

One significant limitation of the health and welfare benefits analyses is the inability to quantify many benefits from reduced emissions of NOx and SO_2. In general, if it were possible to include the unquantified benefits categories in the total monetized benefits, the benefits estimates presented in this RIA would increase. Specific examples of unquantified benefits explored in more detail below include ozone-related benefits, benefits of reduced nitrogen deposition to estuaries, nitrogen in drinking water, other human health effects, and brown clouds.

9.11.1.2.1 Ozone-related Benefits

In addition to reductions in PM, controls employed to meet the illustrative RH visibility goals will also result in reductions in NOx, a precursor in the formation of ozone, which will result in reductions in ambient concentrations of ozone. Due to inadequate modeling resources, ozone reductions are not modeled in this benefits analysis. Possible health benefits associated with reductions in ambient ozone concentrations include avoided incidences of premature mortality, reduced numbers of hospital admissions for respiratory ailments, reductions in incidences of acute respiratory symptoms, and increases in worker productivity for outdoor laborers. Possible ozone-related welfare benefits include increases in yields of commercial crops such as cotton and corn and fruit crops and increases in yields of commercial forests. The magnitude of these omitted benefits is not known. Reductions in ozone may also yield disbenefits, in the form of reduced protection from ultraviolet light, specifically UV-B. The magnitude of this potential disbenefit is not known.

9.11.1.2.2 Nitrates in Drinking Water

Nitrates in drinking water are currently regulated by a maximum contaminant level (MCL) of 10 mg/L on the basis of the risk to infants of methemoglobinemia, a condition which adversely affects the blood's oxygen carrying capacity. In an analysis of pre-1991 data, Raucher, et al. (1993) found that approximately two million people were consuming public drinking water supplies which exceed the MCL. Supplementing these findings, the National Research Council concluded that 42 percent of the public drinking water users in the U.S. (approximately 105 million people) are either not exposed to nitrates or are exposed to concentrations below 1.3 mg/L (National Research Council, 1995).

In a recent epidemiological study by the National Cancer Institute, a statistically significant relationship between nitrates in drinking water and incidence of non-Hodgkin's lymphoma were reported (Ward, et al., 1996). Though it is generally acknowledged that traditional water pollution sources such as agricultural runoff are mostly responsible for violations of the MCL, other more diffuse sources of nitrate to drinking water supplies, such as that from atmospheric deposition, may also become an important health concern should the cancer link to nitrates be found valid upon further study.

9.11.1.2.3 Other Human Health Effects

The benefits of reductions in a number of ozone and PM-induced health effects have not been quantified due to the unavailability of concentration-response and/or economic valuation data. These effects include: reduced pulmonary function, morphological changes, altered host defense mechanisms, cancer, other chronic respiratory diseases, infant mortality, airway responsiveness, increased susceptibility to respiratory infection, pulmonary inflammation, acute inflammation and respiratory cell damage, and premature aging of the lungs and chronic respiratory damage. An improvement in ambient PM and ozone air quality is expected to reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are known to be PM or ozone-induced, concentration-response data are not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects leads to an underestimation of the monetized benefits presented in this analysis.

9.11.1.2.5 Other Unquantifiable Benefits Categories

There are other welfare benefits categories for which there is incomplete information to permit a quantitative assessment for this analysis. For some endpoints, gaps exist in the scientific literature or key analytical components and thus do not support an estimation of incidence. In other cases, there is insufficient economic information to allow estimation of the economic value of adverse effects. Potentially significant, but unquantified welfare benefits categories include: existence and user values related to the protection of ecosystems, damage to industrial materials or national monuments, and reduced sulfate deposition to aquatic and terrestrial ecosystems. Although scientific and economic data are not available to allow quantification of the effect of PM in these categories, the expectation is that, if quantified, each of these categories would lead to an increase in the monetized benefits presented in this RIA.

9.11.2 Why Benefits Estimates May Be Overstated

9.11.2.1 *PM Mortality Risk*

Table 9-27 summarizes a number of the uncertainties associated with estimating mortality risk associated with particulate matter (PM). Most of these uncertainties can serve to increase or decrease the estimated benefits relative to a hypothetical "true" prediction. Some uncertainties may inflate estimates, while others - such as exclusion of effects categories - can result in understatement. The fundamental concentration-response relationships used to estimate benefits are derived from epidemiological studies of community health. Based on these studies and other available information, the EPA Criteria Document concluded that the observed associations between PM and mortality and other serious health effects were "likely causal." The Criteria Document also noted that, as yet, the scientific information did not provide a basis for determining what biological mechanisms might account for such effects. To the extent that some chance remains that no causal mechanisms are found for some PM components or for The PM mix taken as a whole, the benefit estimates derived from the epidemiological studies would be overstated.

Similarly, the evaluation of the epidemiological evidence included an extensive assessment of a number of potential pollutant and weather confounders or effects modifiers. The Criteria Document concluded that these factors could not fully account for the observed PM/effects associations, but it is possible that some portion of the quantitative relationships are affected by the presence of other pollutants. While multiple pollutant effects may be additive, it is also possible that the PM-related effects association may be overstated for some studies which might inflate the benefits estimates derived from such studies.

9.11.2.1 *Full Attainment of the PM and Ozone NAAQS*

As indicated above, incremental benefits attributable to the illustrative visibility goals analyzed for this RIA are dependent on the progress towards those goals made through implementation of the PM and Ozone NAAQS. Due to limits on the ability to model future technology to control emissions in a cost-effective manner, the baseline for this analysis assumes partial attainment of the PM and ozone NAAQS, as was presented in the PM and ozone NAAQS RIA. Because of this limitation, progress towards visibility goals that might have occurred if full attainment of the PM and ozone NAAQS was achieved are not credited to the implementation of the PM and ozone NAAQS. Instead, any additional progress past that achieved through partial attainment of the PM and ozone NAAQS is assumed to be creditable to the RH rule. If full attainment of the PM and ozone NAAQS is assumed, then fewer additional emission controls would be necessary to meet the illustrative visibility goals and thus the incremental benefits attributable to the RH rule would be lower.

9.11.2.2 *Unquantified Disbenefits*

In addition to unquantified benefits, a discussion of potential unquantified disbenefits must also be mentioned. The disbenefit categories discussed here are related to nitrogen deposition. There may be other disbenefit categories which we have not been able to identify. Because EPA is not able to quantify these disbenefit categories, total benefits may be overstated.

9.11.2.2.1 Passive Fertilization

Several disbenefit categories are related to nitrogen deposition. Nutrients deposited on crops from atmospheric sources are often referred to as passive fertilization. Nitrogen is a fundamental nutrient for primary production in both managed and unmanaged ecosystems. Most productive agricultural systems require external sources of nitrogen in order to satisfy nutrient requirements. Nitrogen uptake by crops varies, but typical requirements for wheat and corn are approximately 150 kg/ha/yr and 300 kg/ha/yr, respectively (NAPAP, 1990). These rates compare to estimated rates of passive nitrogen fertilization in the range of 0 to 5.5 kg/ha/yr (NAPAP, 1991). So, for these crops, deposited nitrogen could account for as much as 2 to 4 percent of nitrogen needs. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. The EPA has not estimated the potential value of this possible increase in the use of purchased fertilizers, but a qualitative assessment of several factors suggests that the overall value is very small relative to the value of other health and welfare endpoints presented in this analysis. First, reductions in NOx emissions affect only a fraction of total nitrogen deposition. Approximately 70 to 80 percent of nitrogen deposition is in the form of nitrates (and thus can be traced to NOx emissions) while most of the remainder is due to ammonia emissions (personal communication with Robin Dennis, NOAA Atmospheric Research Lab, 1997). Second, some sources of nitrogen, such as animal manure, are available at no cost or at a much lower cost than purchased nitrogen. In addition, in certain areas nitrogen is currently applied at rates which exceed crop uptake rates, usually due to an overabundance of available nutrients from animal waste. Small reductions in passive fertilization in these areas are not likely to have any consequence to fertilizer application. The combination of these factors suggests that the cost associated with compensating for reductions in passive fertilization is relatively minor.

Information on the effects of changes in passive nitrogen deposition on forest lands and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

9.12 References

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